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Second Series.

VOLUME FOURTEENTH.

LONDON:
H. BAILLIERE, PUBLISHER, 219, REGENT STREET,
AND 290, BROADWAY, NEW YORK.
PARIS: J. BAILLIERE, LIBRAIRE, RUE HAUTEFEUILLE.
1857.

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MANCHESTER:
PRINTED BY T. SOWLER AND SONS, ST. ANN'S SQUARE.

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OF THE

Literary and Philosophical Society of Manchester.

I.—*On Lightning and Lightning Conductors.*

By the late Mr. William Sturgeon.

(Continued from Vol. IX. p. 79.)

52. My own experience, which has been extensive in electro-explorations of fogs, corresponds with that of all other observers. I have found them invariably electro-positive; and in many instances, especially in frosty mornings, the well-known odoriferous character of electricity is so remarkably well developed on the olfactories, that no electrician could mistake it.

53. Haze, also, which occurs during hot weather, and floats higher in the air, and is more attenuated than fogs, I have found to be still more pregnant with intense electro-positive action. In some cases the discharges, through an uninsulated wired kite string held in the hand, have been so copious and rapid, during a haze, that it was impossible to evade a multitude of shocks. They frequently occurred in absolute torrents or vollies.

54. Now, although there may be a difference in the magnitude of the particles constituting fog, haze, and thunder-cloud,

their aqueous character is precisely the same; and it is only the elevated aerial locality and the rapidity with which the latter is formed, that gives it a superior electric tension, and enables it to discharge its electric element with violence in the shape of lightning.

55. With respect to aerial locality or altitude, I believe it is now pretty well understood that the higher regions are more densely charged with the electric element than those below. The experiments of MM. Gay Lussac and Biot, during their memorable balloon excursion in the year 1804, showed that the air, at a lower altitude, was negative to that in which the balloon was floating. The experiments which I have myself made with electric kites, at different altitudes at the same time, have invariably developed similar results: for in every case, during serene weather, the highest kite was positive to those beneath it, and the lowest negative to all those above it; but still positive with respect to the ground on which I was standing. Hence, during serene weather, there appears to be a regular increase of electric charge in the atmosphere, from the ground upwards, as some function of the altitude; and as aqueous vapour suspended in the air necessarily partakes of the same electric character, it is easy to understand that a rapid condensation of that situated at a high altitude would form cloud of a far superior electric intensity to any that could be formed nearer to the ground. Moreover, since in all cases the formation of cloud precedes discharges of lightning, and thunder-storms are frequently attended with the most violent hail showers, even during the hottest weather, there can need no further indication of a thunder-cloud's formation being the effect of a sudden depression of temperature; and, consequently, all thunder-clouds, whatever change they may suffer afterwards, are originally electro-positive. No experiment, that I am acquainted with, can illustrate this fact more correctly than that first shown by Franklin himself, with his chain and can.

56. The principles of electric action enable us to understand that the presence of a highly charged cloud will disturb the previous electric condition of the vicinal air, as well as that of other clouds of lower intensity. In the latter case, the disturbed cloud becomes prepared for the reception of a discharge from that which disturbed it: hence one cause at least why flashes of lightning more frequently occur amongst the clouds themselves than between them and the earth. This tendency to aerial lightning is also enhanced by the abundance of aqueous vapour condensing in the region of the clouds, which affords a conducting medium more easily transpierced than the interposing dry air which separates clouds from the ground, and consequently it is but seldom that lightning strikes terrestrial objects previously to the intervening aerial resistance being in a great measure removed by copious showers of rain.

57. But, notwithstanding the facilities afforded by falling rain, terrestrial objects require a predisposition to receive lightning before it can assail them. This disposition is enforced by the presence of the cloud, which disturbs the *normal* electric state of the air beneath it, by a repellency of its fluid into the ground, which will allow of its intromission in proportion as its surface is prepared for its reception. Now, allowing a plot of ground, or even an extensive tract of country, to be of an uniform conducting quality throughout, its reception for the electric fluid from the air would depend upon the character of its surface; if barren of vegetation, it could not receive the electric fluid with the same degree of facility as when luxuriously clothed with grass, corn, trees, &c., which would present myriads of conducting points and sharp edges in the best possible direction for the electric ingress, and the multitude of roots ramifying into the soil would facilitate its intromission and disposition below the surface.

58. But the electric force of a cloud capable of repelling

the fluid from the non-conducting air into the land, through the medium of its vegetable clothing, would necessarily move it still farther in this better conductor, which would necessarily become electro-negative throughout a much greater area than that presented by the lower surface of the cloud. Hence there appears but little difficulty in understanding why trees, which present multitudes of conducting points and sharp edges to the air, and stand more prominent than the ordinary level of the vegetation, should so frequently be the victims of lightning. It is, however, worthy of remark, that the tallest trees are but seldom selected; and frequently lightning strikes objects closely situated to trees without touching the latter. The nature of the soil, with regard to its conduction, as well as the objects situated on it, has much to do with the reception of lightning, for no object can receive a discharge from a cloud unless it be susceptible of electro-negation by the cloud's repellent force; hence objects situated on wet lands or on the banks of rivers are frequently those which fall victims to lightning. Heavy rains, however, render all objects, as well as the sites on which they stand, conductors, and consequently susceptible of electro-polarisation by the repellent force of a thunder-cloud.

59. Wherever land is impervious to the electric fluid, that in the air above it becomes accumulated in a stratum on its surface on the approach of a disturbing thunder-cloud, and the repellent forces of the positive stratum, and those of the cloud, cause the latter to diverge from the direction of the wind, until it arrives at a locality suitable for the introgression of the disturbed electric fluid of the air. Hence it is obvious that the removal of the electrical resistance of the air is a necessary preliminary to lightning striking objects on the earth's surface, for the force that repels the cloud is that which counterchecks the tendency of lightning discharges.

60. But if a displacement of the electric fluid of the air be a necessary preliminary to strokes of lightning, and it

be facilitated by pointed vegetable conductors, the rule applies to pointed metallic conductors also, and the tendency of lightning towards them will depend on their number and prominency, and the sharpness of their points. Hence those tall conductors which present several pointed branches to the air, are better adapted for facilitating lightning discharges than those that terminate with one point only. Hence also (57) several distinct pointed conductors, distributed over a comparatively small area of ground, or attached to different parts of an extensive building, are more likely to cause strokes of lightning in the locality than one conductor only, though furnished with the same number of points.

61. With respect to the ocean, which is a better conductor than either wet land or lakes of fresh water, its natural electric fluid would be easily displaced by the repellent force of a thunder-cloud, although not so well prepared for the reception of fluid from the air as wet land well clothed with vegetation. The presence of shipping, however, whose masts and rigging stand prominently above the surface of the water, tend much to facilitate those electric intromissions which qualify the air for the transport of lightning from a cloud to its destination; and since every portion of metal in the rigging enhances the conduction, and thus increases the tendency of lightning discharges in the direction of the ship, there appears every reason to infer that those vessels which expose pointed conductors, more lofty even than the masts themselves, are more likely to experience strokes of lightning than any other.

62. The above inference (61) appears to be somewhat countenanced by the "return ordered to be laid before the House of Lords, by precept, dated 4th May, 1848," in which it is shown that sixteen men-of-war, fitted with pointed conductors in the masts, were struck by lightning between March, 1840, and January, 1848. One of these vessels, the *Favorite*, is reported to have been struck "several times," and the *Fisgard* and *Dido* appear to have been struck twice each,

which make the number of cases twenty, by allowing three for the *Favorite*. In addition to these, there appears from another report "prepared in compliance with a precept of the House of Lords," dated June, 1849, to have been five cases (within the same period) of lightning striking men-of-war furnished with *wire-rope conductors*, which make a total of twenty-five cases within a period of eight years. The *Mindon* was struck twice, so that there are twenty-six lightning strokes in the whole.

63. In the absence of official returns to show the effects of lightning, within the same period, on those ships of the royal navy which have not been furnished with conductors, a comparison of the number of cases in which lightning has struck men-of-war, *with* and *without* conductors, may be approximated by taking the mean of the latter class of cases for eight years, out of all those that have occurred within the twenty-four years previous to 1840, which, according to a statement in the *Nautical Magazine* for May, 1844, amount to fifty-two. This gives seventeen cases for each period of eight years, which is about two-thirds only of the number of cases that have occurred to those ships to which pointed conductors are attached, a result by no means favourable to that form of conductors being introduced into the navy.

64. But if pointed conductors tend to favour the approach of lightning towards those objects to which they are attached, *oblique* discharges may find other channels of conduction, amongst those objects over which they pass, the resistance of which, at certain points of the transits, would be more easily vanquished than that offered in a direct line to the conductor itself. For, although a tall pointed conductor might be the principal object in the locality for qualifying the air so as to allow of a discharge taking place, the electrical disturbance caused by the lightning subsequent to its departure from the cloud, and the consequent electro-negations that it would enforce amongst objects within the range

of its influence, might cause it to deviate considerably from the original direction in which it started, and to take a newly-created route to its destination. Hence the probability, at least, that tall pointed conductors are frequently instrumental in bringing down strokes of lightning on vicinal objects as well as on distant parts of those to which they are immediately attached.

65. By taking this view (64) of the operations of lightning during its passage through the air, nothing seems more easy to understand than the cause of so much damage being caused by it close to the site of tall pointed conductors. Nor could anything more decisively discountenance the long-fostered idea that the *path* of lightning and the objects which it strikes are definitely marked out previously to its leaving the cloud.

66. If, therefore, it be allowable to lay to the charge of tall pointed conductors those cases of damage by lightning which have occurred to vicinal objects (19—25, &c.), their reputation, as protectors to shipping, will appear less favourable than from the estimate already made (63). For the cases of damage which would thus be attributed to them would, within a similar period, be more than double the number of those that have occurred in their entire absence, or where they could have no influence whatever.

67. Another important argument arises from the *effects* that lightning has been known to produce on pointed conductors. The most notable of these is the destruction of the points by fusion, in those cases where they have received the discharge. Instances of this kind have been noticed from the earliest period of lightning conductors to the present time. Several have occurred to conductors attached to buildings; and marine conductors have frequently met a similar fate. In the report already alluded to (62), it is stated that in the case of H. M. ship *Constance*, "the *main spindle was*

fused," and that "the conductors on the fore and main masts were fused in several places."

68. In the case of the *Fisgard* (41), the same report states that "the end of the *vane spindle on the main-mast was fused,* and the conductors aloft exhibited small spots of fusion. The copper plates were started from the mast for a few inches, about 13 feet above the deck." The report of Captain Duntze, who commanded the *Fisgard* at the time, is somewhat more minute, and states that the mast itself was "slightly singed" and splintered about the place where the conductor was started from it. (See 41, for further particulars.)

69. With respect to the effects below deck, Capt. Duntze states that, "The electrical current having passed down the main-mast, took the direction of the branches to the bolts through the side,—one leading through the boatswain's cabin, and the other through the midshipmen's berth. The branch conductors in this ship, instead of leading directly to the copper sheathing near the water's surface, as originally proposed, had been led out above it, to two bands of copper passing down externally over the ship's side; these bands were also started at the ends in contact with the termination of the through bolts; the copper sheathing covering the other extremity of the band was bulged outwards. It appears further, by other reports, that at the point of contact with the branches and iron knees within the ship, the metal was blackened, as if a slight expansive action had occurred at these points; this is said to have been more apparent in the boatswain's cabin, and may have arisen from an imperfect contact with the iron knee and through bolts."*

70. The statements in Captain Duntze's report are of an exceedingly interesting character, because of their furnishing the particulars of the several events which occurred during

* Captain Duntze's Official Report. Harris's Remarkable Examples.

the transit of the lightning from the mast-head to the sea, some of which, to an electrician of the present day, would appear to be sufficiently alarming to discountenance *in toto* this particular plan of conductors, notwithstanding that they were originally projected by Mr. Henley, one of the ablest practical electricians of the last century,* who, no doubt, was led into the error from a want of more experience than could possibly be afforded at the time he proposed them. In a paper, by this excellent electrician, which appears in the *Transactions of the Royal Society*, the author states that if instead of chain conductors "plates of copper $\frac{1}{10}$in. thick and 2in. broad, with the edges neatly rounded off, were inserted in a groove and continued down the main-topgallant-mast, the main-topmast, and part of the main-mast, into the well-hole; a communication from the mast to the underside of one of the decks might be made with a plate of metal flattened at each end, and from that rod the conductor might be continued by plates of lead or copper on the underside of the deck and down both outer sides of the ship as low as the keel, if it be thought necessary; and this method, I should apprehend, would be preferable to the chains, now in use. Particular care should be taken to have all the plates which form the conductor as nearly as possible in contact with each other, and to fix a sharp pointed slender rod of copper at its summit. And, for the purpose of connecting the plates inserted in the main-topgallant-mast, the main-topmast, and main-mast, if a hoop of copper were fixed in a groove of its own thickness at the top of the main-mast, and another such hoop at the upper end of the main-topmast, perhaps they might answer this end very conveniently."

71. It seems pretty clear, from Captain Duntze's official report alone, that explosions took place below deck as well

* See Mr. Henley's paper on this subject, in the Philosophical Transactions of the Royal Society for 1774.

as on the mast above, for nothing less than a high degree of temperature, occasioned by an explosion, could blacken the metal at the junction of the iron knees with the branch conductors. And this view is still further supported by a letter (from an officer belonging to the ship) that appeared in the *London Illustrated News* for March, 1847, in which it is stated, that "on reaching the lower deck the discharge took the branches under the beams leading to the bands on the ship's sides; *these were started* at the ends in contact with the copper bolts leading to the sea, and the copper sheet covering the joint was *bulged upwards* by the expansive force of the shock."

72. Nor is this a solitary case of explosions occurring below deck, by lightning traversing the branch conductors. In the case of H. M. ship *Constance*, already alluded to (67), it is officially reported, that besides the injury the conductor received on the mast, the lightning *slightly* tore "away part of the casing which covered the branch conductor in the boatswain's cabin, close to the side where it escaped."* H. M. ship *Fox*, 44 guns, was struck by lightning April 5th, 1847. "Lightning passed down the chain conductor, *passing visibly through midshipmen's berth* and *Commodore Steward's berth*, and leaving a *burnt mark*."† H. M. ship *Conway*, 26 guns, was struck by lightning March 9th, 1846. The electric fluid "traversed the branch or beam in the gunner's cabin, who experienced no ill-effect; he saw it pass from the ship in a blaze of light. Mr. Lethbridge, officer of the watch, then on deck, describes the effect as if *one or two of the main-deck guns* had been *fired up the hatchway*."‡

73. The effects thus described to have taken place *below deck* (67—70), are of a similar character to those observed on the masts above deck; and from the same cause, viz., a want

* Official Return, prepared in compliance with a precept of the House of Lords. Dated 11th June, 1849.

† Ibid. ‡ Ibid.

of continuity in the metallic channel, which will always allow of explosion when lightning discharges traverse conductors made up of metallic plates. Hence the separation of "the plates of copper forming the conductor" of the main-mast ot the *Fisgard* (41), and of those also in the branch conductors as well as the starting of the copper bands from the exterior ends of the through bolts, and the bulging *outwards* of the copper sheathing (69), were results that might easily have been foreseen as some of the natural consequences of such explosions.

74. But if an ordinary discharge of lightning is capable of producing such fearful explosions within the ship, and ruptures in the conductors and copper sheathing, we have only to allow of a second discharge of lightning to strike the ship before the injured conductors were repaired, to form a picture in the mind of the serious consequences likely to ensue. Ruptures partially accomplished by the first discharge would be completed by the second, and former breaches would be widened; and many dangerous explosions, both above and below deck, would probably take place.

75. Should this plan of conductors be introduced to the merchant navy, there would be no predicting the evils that might arise, even from the first flash of lightning that traversed them, especially when the cargoes consisted of cotton-wool, hemp, flax, &c., close jambed against the branch conductors at those places most likely to experience explosions. And as it would be next to impossible to accomplish a minute inspection of these branch conductors when most necessary, the chances of avoiding danger from subsequent strokes of lightning would be much less than in men-of-war, where every facility for discovering breaches in the conductors, and of repairing them by competent hands, is always afforded.

76. It appears, therefore, from a due consideration of all the facts that experience has hitherto furnished, that there

are two fundamental errors, fraught with great danger, in this plan of conductors, the most palpable of which is that of leading the lightning into the hull of the ship, and then having to incur a heavy expense in endeavouring to get it out again. The other is that of having the conductors compounded of many constituent pieces, although copper, of any required dimensions and form, is always procurable.

77. Although I am far from thinking that conductors let into the masts are the best situated for protecting ships from lightning, still, should that plan continue to be persevered in, they ought not, under any consideration whatever, to proceed downwards on the masts farther than the upper deck. With conductors thus applied, there could be no apprehensions entertained of explosions taking place below deck, nor of chronometers being injured by the magnetizing influence of lightning, which is also a consideration of importance. Moreover, as each individual mast would have an uninterrupted conducting flat metallic rod throughout, there could be no explosions in the circuit excepting such as might occur at the juncture of the rods, at the heads of the lower and top-masts, or at those other places where lightning might strike the mast below the highest point. The examination of those parts, and their repairs, if necessary, would require neither much time nor skill to accomplish.

78. I am not aware of the manner in which the wire-rope conductors have been attached to the several men-of-war that have been fitted up with them; but it appears, by the official report, that although they have answered the purpose exceedingly well in some cases, they have entirely failed in others. Commander Darley, of H. M. ship *Electra*, reports favourably of these conductors, having observed their efficiency in carrying off several discharges of lightning, whilst on the West India station, in the year 1842. But, on board the *Hazard*, where similar conductors were employed, they have failed to protect the ship on two occasions, viz., May 1st and

June 12th, 1846. It is worthy of remark, however, that although the mast and some parts of the rigging suffered much from the lightning, it was safely conducted overboard on both occasions. The damage suffered by the *Hazard*, June 12th, 1846, is very likely to have arisen from these very circumstances. "Lightning struck the ship, splitting and carrying away main-topgallant and royal-mast, the whole of the main-topmast from the hounds to the lower cap, damaging the top, and sprung the after cross-tree, split and carried away starboard tressel-tree; a splinter from main-topmast passing through the starboard side of the quarter-deck, the electric fluid escaping from the conductor by the main rigging overboard." In this case, nothing is said about injury to the wire-rope conductor, which, no doubt, was on the opposite side of the ship to that on which the lightning entered the rigging; and it is very likely that the lightning was very much attenuated amongst the masts and other parts which it destroyed or damaged, before any part of it arrived at the conductor. Indeed, the whole force of the discharge could never arrive at the conductor, because much of it would be carried off by the main-mast to the deck, and thence to the sea.

79. If the *Hazard* were fitted with conductors in the manner that Commander Darley describes those of the *Electra*, viz., one to each mast, they would be still more liable to entail danger on the rigging than conductors fitted into the masts; because an approaching discharge from the other side of the ship, if it did not attack the conductor at the mast head, would have to pass through some part of the rigging before it could arrive at it. This must always be the case where the rigging is protected on one side only.

80. But there are other serious objections to the wire-rope conductors, (unless very differently applied than on board the *Electra*,) which Commander Darley says "are composed of copper wire-rope, one to each mast; they are passed through

the mast head, trucks, and caps, and lead down the back-stays through the channels, and are attached to a copper plate secured under the ship's copper." *

81. The principal defect in the present fashion of the wire-rope is the diminutive size of its strands, which are easily fused individually, on that side especially which receives the lightning stroke; and if the discharge be very formidable, the whole of the strands might be blown to atoms, or torn asunder at the point which received it. Such seems to have been the case with the conductor of the *Hazard*, for on one of the occasions when the ship was struck by lightning, it "carried away the conductor at main-topgallant-head." † The wire-rope at present in use, besides the defects already pointed out, is twisted a great deal too much, for it requires a greater length for the strands than there is need for, and the more compact they are laid together (for they can never form one solid body) the more subject they are to be blown asunder by lightning. The only object for having wire-rope is to maintain pliability, which is attainable to any required extent for marine conductors, by the employment of thicker strands, which would be easier laid or twisted together.

82. But as oblique discharges of lightning frequently strike conductors below the mast-head, wire-rope will always be liable to damage under these circumstances, because some of its strands are almost sure to suffer by every formidable discharge. The only danger, however, would be at the point of attack, which is more likely to be sustained by moderately thick wires than by thin ones; but, in all cases, both sides of the rigging ought to be protected (76), and the conductor on each mast ought to be metallically connected at the cross-trees and at the tops, as well as at the topgallant-mast-heads. By these means, oblique flashes of lightning, from whatever

* Return, &c., prepared in compliance with a precept of the House of Lords Dated 18th June, 1849.

† Ibid.

quarter they came, would meet with conductors without having to enter the rigging, and the conductors would act in concert, each branch carrying off a portion of the discharge; and if to these, other conductors were to connect the several pairs of starboard and larboard conductors, either along the stays or otherwise, the whole system would act in concert, so that however formidable the attack might be on any one point, the distribution would be general throughout the system, and the discharge into the sea from each individual branch would be perfectly harmless. A want of metallic connection above the lower masts of the several conductors attached to the masts individually, is a serious error, whatever may be the character of those conductors or the plan of fitting them up. For whilst they are insulated from each other, they act separately and independently, and derive no conducting assistance whatever from each other, each having to sustain the whole force of the lightning that strikes it, from the point of attack to the sea.

84. There is also an objection to the method of applying the rope conductor to the mast-head, as described for the *Electra* (77), because of the interruption that must necessarily occur betwen the rope and the pointed vane spindle. For, whenever lightning strikes the spindle, there will be an explosion between it and the rope which may be sufficiently formidable to destroy the rope at that place. It is even probable that this was the case when H. M. ship *Hazard* was struck, May 1st, 1846 (79), for the *Report* states *that* the lightning "carried away conductor at main-topgallant-head."

85. From the fact that the points of conductors are frequently fused by lightning, and the great probability, at least, that pointed conductors predispose their localities for the reception of lightning, and thus facilitate its discharges in their own direction, there appears good reason for abandoning the employment of points altogether. For if they had

answered even any of the purposes for which they were first introduced, the first flash of lightning that any of them received would destroy it. Such an accident on board of ship might be but of little consequence, because the vane-spindle being accessible could easily be pointed anew; but a similar accident to the conductor of a tall factory chimney, would entail a heavy expense in scaffolding, &c., before the top of the conductor could be arrived at; so that the supposed virtues of points is an expensive treasure, in continual jeopardy. Moreover, as there has never yet been an instance known of pointed conductors abating the violence of lightning discharges, there is not an attribute belonging to them, nor a recorded circumstance in their favour, that can justify a continuance of their employment in preference to conductors of other forms at their superior extremities; whilst the grave charge of their being instrumental in facilitating strokes of lightning, almost imperatively demands their immediate and total discontinuance.

86. Notwithstanding the attempts that have been made to propagate the idea that *balls*, surmounting conductors, are virtually *points*, when compared to the immense surface of a thunder-cloud, and (by inference) act in a similar manner, the result of Franklin's experiment with the point and head of a pin alternately presented to the prime conductor of his machine would, independently of any other fact, be sufficient to show the fallacy of the hypothesis. But the inaptitude of polished balls in drawing off the electric fluid from vicinal bodies, or intromitting it from the air, is a fact too well established at the present day to admit of either equivocation or doubt. Hence such terminations to conductors are incapable of qualifying the air beneath a thunder-cloud for the transmission of lightning; and consequently have no power in predisposing the locality for its reception. These negative qualifications, in connection with the certainty of their with-

standing any flash of lightning that may assail them, are strong recommendations for the employment of globular terminations to conductors. They offer precisely the same amount of protection as pointed conductors, should lightning come in their way, whether the discharges be vertical or oblique; and as they can never be accessory to its approach, they possess important advantages over those of the usual form.

87. I know of no better *general* guide for the application of lightning-rods, than that embraced in the following motto: *Offer no facilities for the approach of lightning; but prepare for its reception in case it comes.*

88. With respect to the practical application of conductors to buildings, no individual plan will answer for every fashion of edifice. The most simple *systems* of conductors are those that would be applicable to cottages, powder magazines, steeples, tall factory chimneys, &c., for which some general rules might be given; but buildings with complicated irregular roofs, and decorated gables, chimneys, &c., would require a peculiar plan of conductor for each fashion of house. But no building, however plain in its structure, can be rendered secure against lightning by one individual rod only.

89. I have devised the following system of conductors for powder magazines. It consists of three vertical arches of cylindrical copper rod, which are united by a horizontal rod of the same metal, and furnished with three balls.

90. Steeples, of the form of square towers, ought to have a vertical copper rod at each angle, united by a copper band at the top, or just above the uppermost weather mouldings. The vertical rods should reach to above the highest pinnacles, and be surmounted with copper balls; or the whole might unite in one ball directly over the axis of the steeple.

91. Spires may be protected by three copper rods united in a ball at the apex of the cone, and reaching downwards,

at equal distances from each other, to the base, where they should be again united by a copper band. From any part of this band a single rod, reaching to the ground, would complete the conducting system.

92. Tall factory chimneys would require three rods from top to bottom. They should be united in a ball directly over the axis of the chimney, in the fashion of a bird-cage, and again by means of a copper band about half-way between the coping and the ground.

93. In all cases of applying conductors to buildings, the rods should be kept clear of the masonry, at least 3in. or 4in., which may easily be accomplished by allowing them to pass through oaken holdfasts built into the wall. There can be no reason shown for the employment of deep pits or wells, for the reception of the inferior extremities of conductors, where brooks, drains, or gutters are near at hand; for lightning can be safely dismissed by continuing the rods horizontally, just beneath the surface of the ground, to a few yards from the building, and terminating them by a number of sharp metallic points in any of those channels, which are almost sure to be well supplied with water before any lightning descends from the clouds.

94. By employing a *system* of conductors, instead of a single rod, protection is insured against oblique discharges, from whatever quarter they may proceed, and the union of the several branches allows of a distribution of the force throughout the whole system. The spire turret of St. Chad's Church, Cheetham Hill Road, Manchester, which was much injured by lightning on the 23rd of May, 1850, has been furnished with a system of conductors, similar to that described (91), under my own superintendence. The *main* rod, which reaches from the base of the spire to the ground, is continued about 6 yards under ground, at right angles from the side of the tower, and is bent down into a water-drain.

95. A circumstance of an exceedingly interesting character, and replete with valuable instruction, occurred when this church was struck by lightning. When the lightning left the injured turret, it sprang from one iron cramp to another, demolishing the elegant ornamental masonry on the parapet on its way to a leaden gutter, which conducted it to a cast iron water-pipe situated in one of the angles of the tower, and reaching from the top down to the roof of the church, round which are leaden gutters for conveying the rain-water to other cast iron pipes which reach the ground. Whilst on the top of the tower, examining the nature and extent of the damage, I had some difficulty in discovering the route of the lightning, until the sexton who was with me, informed me of the iron pipe inside of the tower. On returning to the bell-loft, I examined the water-pipe very minutely, under the expectation of finding it damaged by the lightning, but I could not discover the slightest breach; the sexton told me that a great quantity of water had fallen on the floor below (the floor of the ringing loft), but it was not known where it came from. We descended to the place, and I soon discovered that one of the pipes was broken and a large piece of it was missing. On looking on the floor at the opposite angle, we found several fragments of the pipe which had been blown from the injured part. At my request, the remaining portions of the cast iron pipe were examined, from the top of the steeple to the ground, and three or four of the *lengths*, at their junction with one another, were similarly damaged.

The suspicion of some damage having been done to this water channel, arose from my knowing that the several *lengths* of which it is composed are insulated from one another by means of the cement (generally stiff white-lead paint) employed at the joints, for rendering those parts water-tight. These interruptions in the circuit will always be liable to lightning explosions; and, of course, endanger the pipe at

every joint. Nor does a full flow of water through them appear to render sufficient assistance to prevent their being damaged, for, in this case, the rain was falling in torrents during the whole time that lightning was in the neighbourhood of the church, and the pipe must have been conveying a copious stream at the time it was damaged. It is probable, indeed, that the presence of a stream of water would increase the danger; because of a sudden production of steam by explosions at the joinings of the *lengths*.

It is worthy of remark, also, that this iron pipe is comparatively new, for the church has not been finished more than about three years. I have some of the fragments in my possession at this time, and I find they are painted black outside, and are perfectly sound on the inner side. I observe, also, that the *lengths* have been painted before being fitted into each other; so that they are insulated from one another by a coat or two of paint in addition to cement.

This circumstance is, I believe, the first of the kind that has been noticed; but it is too important to allow of its omission in this place. The rule which has, for a whole century, guided lightning-rod manufacturers, to avail themselves of every portion of metal that may happen to be conveniently attached to the building can no longer be depended on for protection; for, unless every portion of metal thus employed, were securely and perfectly united, explosions might take place on the roof, or against the walls, which would be productive of serious damage.

The spire, and other portions of St. Chad's Church (95), as has been the case with many others, suffered by explosions from metal to metal; and if a second discharge of lightning had passed along the broken water-pipe before the damage occasioned by the first had been repaired, the explosions at these interruptions in the circuit would probably have displaced large portions of masonry from the tower, as

well as from the side wall of the church, against which the pipe is placed.

I should be exceedingly glad to hear that the description of this event, and the remarks I have made upon it, were the means of providing better security to her Majesty's palace at Osborne, than that afforded by cast iron water-pipes, eight or nine of which are now jeopardising the building, by being employed as portions of as many distinct lightning conductors.

II.—*On some Peculiarities of the Thunderstorm which occurred in this neighbourhood on Tuesday, the 16th of July last.*

By the late Mr. William Sturgeon, Prestwich.—(Communicated by Mr. Joule.)

[*Read March 4th*, 1856.]

The principal characteristics, of this storm, that I have to notice in this communication, are, unusual displays of lightning, and the effects of electrical disturbances caused by it at a distance from the primitive discharge.

This storm, which commenced in the afternoon, was experienced on every side of Manchester at nearly the same time. On the road near to Bury, the lightning killed a young man and the horse he was riding on. It was exceedingly violent over Bolton and Blackburn; also at Liverpool and Northwich. As the principal part of the storm never reached this place, I had an opportunity of exploring the atmosphere, by means of an electric kite, without apprehension of danger, although many thunder-clouds passed slowly over during the time. I got the kite afloat, with 300 yards of string out, a little before six in the evening, and kept it up till nearly eight. During this time the storm was raging over Bolton. The lightning was very frequent and brilliant, notwithstanding the bright daylight it had to contrast with.

The discharges from the kite-string were occasionally both frequent and powerful, and at other times, but seldom and feeble; which is frequently the case in the vicinity of thunderstorms. But in all cases, whether the sparks were large or

small, they were invariably positive; showing that the air, in this instance, retained its *normal* electric character (its electric state during severe weather), though much disturbed by neighbouring clouds and distant lightning. With respect to the disturbance from the latter cause, it was very marked on the present occasion, and its effects, in some of the instances I have to mention, although not often observed, are such as are always to be dreaded from vicinal flashes of lightning.

During my experiments at the kite-string, I had the company of the Rev. W. W. Johnson, who assisted me in carrying them on. After ascertaining the electric state of the air and its vacillating intensity, my attention was drawn to the distant lightning, which was now very fine; and its disturbing influence was soon discovered to extend to the place of observation. The wire connected with the ground was placed at a certain distance from the conductor of the string, and the frequency of the sparks observed. At times no sparks were transmitted, at other times an abundance of them were discharged through the interval within a few moments. On comparing these fluctuations with the intervals between the lightning flashes, we each took a separate part in the observations. I looked out for the lightning, and announced each flash by the word "*when;*" whilst Mr. Johnson kept his eye on the apparatus. Whilst I was silent, scarcely any sparks appeared; but a shower of them were discharged from the kite-string whenever I announced a flash of lightning: thus showing by the concurrence of the events, that there existed a rigid connection between the *primitive* and *secondary* discharges.

Phenomena of this class are by no means of recent discovery, though not often shown in this manner; and have generally been considered as *primitive* rather than secondary events. The easiest way of ascertaining an electric disturbance, by the influence of a distant flash of lightning, is by

holding the base of an electroscope in the hand, and elevating it in the air above the head during a thunderstorm; every flash of lightning will produce a sudden divergency of the gold leaves. When the lightning is near, the disturbance is too powerful for a delicate electroscope to withstand.

On the day following that of the storm, I had information of a cotton mill being set on fire by the lightning, at Bolton. I immediately proceeded to the place, for the purpose of examining the effects of the lightning on the mill, which I found to belong to Messrs. Bolling and Co., and situated in Bradshaw-gate. By the kindness of the foreman I soon gained admittance, and had every attention paid to my inquiries. I was shown that part of the machinery which had been on fire, but no indication could be found of lightning having entered the building.

The damage was very trifling, being limited to a carding machine and a few boards of the floor above, which were charred by the fire. This limitation of the damage, however, was owing to an incidental circumstance which fortunately occurred, otherwise it is probable that the whole of the premises would have been destroyed.

The rule observed at the mills is to turn off the steam-power at half-past five daily, and the people leave the place at six. On this occasion, however, the rain was so unusually heavy, and the lightning and thunder so terrific at six o'clock, that no one would venture out. Shortly after six, a terrific flash of lightning took place, attended by a crash of thunder; and immediately an alarm was given that the mill was on fire. Water buckets were immediately served out, and all who could assist were employed in extinguishing the fire, which was accomplished within a few minutes, and before it had time to spread far from where it began.

The very natural conclusion was that the mill had been struck by the lightning, though no breach could be discovered in the roof or walls, nor was a pane of glass disturbed. I

made very particular inquiry about every circumstance that occurred that I considered of importance; all hands thought the mill was struck, but nobody could find the place. Some thought the whole building was on fire for a moment, and those in the rooms thought the lightning struck every part of the machinery. The fact is, the lightning never entered the building at all; and it is obvious, from all the circumstances of the case, that the fire originated from a disturbance of the electric element naturally belonging to the machinery; probably by the influence of the individual flash of lightning already alluded to. Such a disturbance amongst the metallic parts of the machinery would probably give rise to multitudes of sparks, each of which would be sufficient to ignite cotton, wool, or other inflammable material, that happened to be in the way; and, as in this case, the fire originated amongst some loose cotton attached to the carding machine, it is easy to understand how its ignition occurred. I was particularly anxious to ascertain the initial point of ignition, and from the information I received respecting the burning cotton, and the communication of the fire to the floor above, the lower surface of which being that only which had suffered, there appeared no difficulty in understanding where the fire originated.

In addition to the indications already noticed, I had direct evidence of the existence of sparks by their effects on a roller closely situated to the site of the fire, but not in immediate connection with it. This roller is of wood, about 4in. long, and 1¼in. diameter; its hollow axis is filled with lead, and its surface covered with flannel. (I am not aware of the name of this roller, but I send it with the paper for inspection.) The several singed spots on the flannel covering are so many evidences of local fires on the roller's surface, which could not be produced by any ordinary mode of ignition. Nor can it be supposed for a moment that the fire originated from friction, because the machinery had been at rest for more than half an hour; besides which the parts ignited on this roller are not

such as would be likely to be produced by friction, if even it had been in motion. Moreover, the motion of this part of the machine being slow, and its surface not very inflammable, its ignition from friction seems quite out of the question.

From this mill I was directed to another, situated in Halliwell-street, and belonging to Mr. Thomas Cross, which I was told had been set on fire by the lightning. As the people were leaving work when I arrived, my only guide in the mill was the porter, who, after a barrier of prejudice and prudent caution had been removed from between us, became exceedingly polite and communicative. The occurrence here seemed to be simultaneous with that at the other mill. I was first shown a broken window at the landing to the uppermost floor of that part of the mill, and also a rupture of the plastering in the corner close to the ceiling. Only a small portion of plaster was displaced, but the stones* which it had covered were partially shattered. This damage was directly over the burner of a thin leaden gas-pipe, and about two feet from it. As no other damage could be discovered, it appeared obvious that an explosion had taken place between the wall and the gas-pipe; and as no mark of fusion could be discovered on the metal, the quantity of electric fluid transmitted was not great. The explosion, however, would produce a momentary expansion of the air, which would be sufficiently violent to break the window. My guide, however, insisted that the lightning had come through the window, and had melted the glass into smoke, for not a single fragment of it could be found. I told him to look outside on the window-sill, and perhaps he might find some, which he soon discovered to be true; but what astonished him most was, how I, who had never been in the mill before, should know where to find the broken glass. After allowing him to exercise his imagination for a minute or two, I relieved him by pointing out the cause.

* It is a stone building.

He became quite delighted with this piece of information, and immediately took me to another part of the mill where a quantity of cotton had been set on fire on the drums of two carding machines. This accident occurred close to a window which had suffered no damage whatever, nor was there to be found any trace of the *direct* action of lightning. The two drums on which the cotton was ignited are distant about forty yards from the gas-pipe already mentioned, and as the fluid that struck the burner would follow the pipe to the ground, which was in a direct line downwards to the metre on the ground floor, and thus to the underground main, it would be impossible to imagine that any *direct* action from that flash of lightning on those distant carding machines could take place; and, as not the slightest damage was done to any part of the mill beyond that already mentioned, at the distance of forty yards, there appears no other mode of accounting for the fire than that arising from a consideration of the effects of electrical disturbances by vicinal flashes of lightning.

These effects of electrical disturbance are in direct correspondence with many others, of the same class, that have been observed, but hardly ever clearly accounted for. Such are deaths from lightning where no external marks of violence appear on the subjects; the singeing of garments without injury to the wearer, beyond that of a momentary shock, &c. In many cases, however, the expansion of the air and the sudden conversion of fluids into steam and gases are productive of much damage, and even of death.

Every flash of lightning necessarily disturbs all the electric fluid around it, and thus produces an *electrical wave*, which, in some instances, reaches to great distances, causing a sudden increase of pressure, and a consequent intromission of fluid to the ground through the conducting vegetable points and sharp edges with which it is covered. Now, we have only to imagine a tree, which exposes a large area of foliage from its branches, to be situated near to the track of a heavy flash

of lightning, to form an idea why the trunk should be decorticated and split to shivers, whilst no mark of violence appears on the leaves and branches; for the suddenly disturbed electric element in the vicinity of the tree would find an easy ingress through the medium of the foliage, which, in consequence of each leaf and point introducing but a small portion of the whole that entered the tree, would not suffer by the transmission from the air; but as the whole of these portions would arrive at the trunk at the same moment, they would form a formidable mass of the electric element, sufficient to convert the sap into steam, with an expanding power that would accomplish the tree's destruction in a moment.

But to return to the Prestwich observations. After leaving the ground where the kite experiments were made, the lightning appeared so unusually fine that I was induced to observe it for a long time; and as the flashes, or rather streams, of electric fluid were each of longer duration than any I had previously seen, I stept into the house for a pendulum to ascertain the time which each discharge occupied, and found that, in some cases, the electric fluid was visible during a second and a half. Most of the discharges seemed to be at great altitudes amongst the clouds, and had a fiery red appearance; and as several appeared to shoot upwards, they, according to the rules of perspective, proceeded *towards* the place where I was standing. Many discharges, however, took a horizontal direction at right angles to the former, and others were seen to shoot obliquely in various directions. The streams of electric fluid were of unusually large diameter, and seemed like streams of liquid fire; and in some instances they looked like sky-rockets, with a burst of multitudes of stars. Upon the whole, this was the most singular display of lightning I ever beheld.

III.—*On the Comparative Value of various kinds of Stone, as Exhibited by their Powers of Resisting Compression.*

By W. Fairbairn, F.R.S., &c.

[*Read April 1st*, 1856.]

Our knowledge of the properties of stone, viewed as a building material, is very imperfect, and our architects and stonemasons have yet much to learn concerning the difference between one kind of stone and another, both as regards their chemical constitution, their durability, and their powers of resisting compression. On this subject we have the experiments of Gauthey, Rondelet and Rennie, which to some extent supply the deficiency and furnish data for the resistance to a crushing force of a considerable variety of stone. These are, however, to some extent inapplicable to the purposes for which such data are required, and not finding them in exact accordance with the results of some experiments recently made, I have endeavoured to inquire into the causes of the discrepancy, and to account for the difference.

Stone is found in various forms and conditions, embedded in and stratified under the earth's surface. That portion of it which is used for building purposes, is a dense coherent brittle substance, sometimes of a granulated, at others, of a laminated structure. These qualities varying according to its chemical constitution and the mode in which it has been deposited. Sometimes the laminated and granular rocks alternate with each other; at others, a rock of a mixed form

prevails, partaking of the characteristics of both structures. Independent of these properties is its power of resistance to compression, which depends chiefly upon its chemical combinations and the pressure to which it has been subjected whilst under the earth's surface from the weight of superincumbent materials. The granite also, and other igneous rocks, owe their hardness to their having crystallized more or less rapidly from a fused mass.

In attempting to ascertain the ultimate powers of resistance of rocks which have been deposited by the action of water, it is necessary to observe the direction in which the pressure is applied, whether in the line of cleavage, or at right angles to it. In nearly all of the following experiments this precaution was attended to, and it will be seen that the strength is far greater when the force is exerted perpendicularly to the laminated surface, than when it is applied in the direction of the cleavage. In building with such stone, it is also important that it should be laid in the same position as that in which it is found in the quarry, as the action of rain and frost rapidly splits off the laminæ of the stone when it is placed otherwise. The strength of the igneous, or crystalline rocks, is the same in every direction, owing to the arrangement of the particles of which they are composed.

It might have been advantageous to have ascertained, by analysis, the chemical composition of the substances experimented on; but as this varies in almost every locality, and that in accordance with the superincumbent and surrounding strata, this is of less consequence in practice than a knowledge of absolute facts in connexion with the properties of the material. Deductions from direct experiment are of no small importance to the architect and builder, as he should not only be acquainted with the strengths and other properties of the material on which he works, but also with the changes of those qualities under the varied forms of stratified, metamorphic, and igneous rocks.

On the durability of the specimens, I have made no further inquiry than in regard to their power of resistance to strain. Any addition would require a separate investigation into the chemical constituents of the different specimens, and into those changes to which stone of almost every description is subjected when exposed to the action of the atmosphere. In omitting this branch of the investigation I have not forgotten its importance, but have very properly left its development to abler hands.

Before giving the results of the inquiry, I may observe that a portion of the experiments were undertaken at the request of Mr. E. W. Shaw, the surveyor of the borough of Bradford, in Yorkshire, in order to ascertain the best and strongest qualities of stone for paving the streets of that town. The following tables give the result of the experiments on fifteen specimens of Yorkshire sandstone, and on some specimens from Wales and other places, as follow.

Experiments to determine the force necessary to fracture, and subsequently to crush, 2in. cubes of sandstone from the Shipley quarries, Bradford. The pressure applied in the direction of the cleavage.

No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.
Specimen No. 1. Shipley.			Specimen No. 2. Heaton.			Specimen No. 3. Heaton Park.		
12	31732		11	31732		8	26356	
13	33524	fractured	12	33524	fractured	9	28148	
...	.....	.....	...	.....	.....	10	29940	fractured
16	38900	crushed	16	40692	crushed	11	31732	crushed
Specimen No. 4.			Specimen No. 9. Old Whatley.			Specimen No. 10. Manningham-lane.		
This specimen was defective and crushed as the first weight, 28148 lbs., was laid on.			11	31732		8	26356	
			12	33524		9	28148	fractured
			13	35316 & crushed	fractured suddenly.	...	.....	.....
						14	37108	crushed

The results of the experiments 1, 2, 3, 9, 10, fractured and crushed in the line of cleavage, are given in the following table.

No. of Specimen	Locality.	Size.	Weight at which it fractured.	Weight at which it crushed.
1	Shipley, Bradford.	2in. cube	33524	38900
2	Heaton.....	,,	33524	40692
3	Heaton Park.....	,,	29940	31732
9	Old Whatley.....	,,	35316	35316
10	Manningham-lane..	,,	28148	37108
	Mean.		32090	36749

Experiments to determine the force required to fracture, and subsequently to crush, 2in. cubes of sandstone from the Shipley and other quarries, near Bradford. Pressure being applied at right angles to the cleavage.

No. of Expt	Weights laid on in lbs.	Remarks.	No. of Expt	Weights laid on in lbs.	Remarks.
Specimen No. 5. Idle Quarry.			Specimen No. 6. Jegrum's-lane.		
15	38900		18	44276	
16	40692		19	45172	fractured.
17	42484	fractured.	...	.....	.....
18	43380	crushed.	22	47860	crushed.
Specimen No. 7. Spinkwell.			Specimen No. 8. Coppy Quarry.		
10	29940		14	37108	first fracture..
11	31732	fractured.	...	.... .	.....
...	.....	.....	16	39796	second fracture.
14	37108	crushed.	...	.....	.....
			18	41588	crushed.
Specimen No. 11 failed.					

Results of experiments on specimens 5, 6, 7, 8, fractured and crushed at right angles to the cleavage.

No. of Specimen	Locality.	Size.	Weight at which it fractured.	Weight with which it crushed.
5	Idle Quarry, Bradford.....	2in. cube.	42484	43380
6	Jegrum's-lane.....	,,	45172	47860
7	Spinkwell.....	,,	31732	37108
8	Coppy Quarry.....	,,	37108	41588
	Mean.		39124	42484

By the foregoing experiment it will be observed that the resisting powers of stone to compression, are greatest when the pressure is applied perpendicularly upon the bed or laminated surface, and that in the ratio of 100 : 82 in the force required to fracture, and 100 : 86 in the force required to crush this description of stone. Hence, as already observed, the powers of resistance of every description of laminated stone, are most effective when the beds are placed horizontally or perpendicularly to the direction of the pressure, and this position is the more important when the stone is exposed to the atmosphere, as it partially prevents the absorption of moisture, which in winter tends to destroy the material by the contraction of the stone and the expansion of the water at low temperatures.

Experiments to determine the force required to fracture and crush 1in., 1½in., and 2in. cubes of stones from Scotland, Wales, and other places.

No. of Expt	Weight laid on in lbs.	Remarks.	No. of Expt	Weight laid on in lbs.	Remarks.
Specimen No. 12. Grauwacke. Penmaenmawr, Wales. 2in. cube.			Specimen No. 14. Granite. Mount Sorrel. 2in. cube.		
16	40692	slight fracture.	19	46068	
...	.....	.....	20	47860	
29	63988	second fracture.	21	49052	
30	65780		22	51444	fractured, and after a slight rest crushed.
31	67572	crushed.			

No. of Expt	Weight laid on in lbs.	Remarks.
Specimen No. 15. Grauwacke. Ingleton. 2in. cube.		
13	35316	first fracture.
...	.....	.....
20	47860	second fracture.
...	.....	.....
25	53236	not crushed.
Specimen No. 17. Syenite. Mount Sorrel. 2in. cube.		
17	42484	
18	44276	
19	46068	
20	47284	crushed.
Specimen No. 19. Furnace Granite. Inverary. 1½in. cube.		
4	19188	
5	20980	
6	22772	
7	24564	crushed.
Specimen No. 21. Limestone. B. 1½in. cube.		
1	13812	
2	15604	
3	17396	fractured.
4	19188	crushed.
Specimen No. 23. Magnesian Limestone. Anston. 1in. cube.		
1	1258	
2	2154	fractured.
...	.....	.....
10	3050	crushed.
Specimen No. 25. Sandstone. 1in. cube.		
8	2938	
9	3050	fractured.
...	.....	.....
13	3498	crushed.

No. of Expt	Weight laid on in lbs.	Remarks.
Specimen No. 16. Granite. Aberdeen. 2in. cube.		
8	26356	
9	27546	fractured.
10	28148	
11	28340	not crushed.
Specimen No. 18. Granite. Bonaw. 1½in. cube.		
2	15604	
3	17396	fractur'd in 2 nearly eq. pts.
...	.....	
7	24564	crushed.
Specimen No. 20. Granite. A. 1½in. cube.		
4	19188	
5	20980	
6	22772	fractured.
7	24564	crushed.
Specimen No. 22. Limestone. C. 1½in. cube.		
2	15604	
3	17396	
4	18292	fractured.
5	19188	crushed.
Specimen No. 24. Magnesian Limestone. Worksop. 1in. cube.		
13	3834	
14	3946	fractured.
...	.....	.....
38	7098	crushed.
Specimen No. 26. Sandstone. 2in. cube.		
11	9770	
12	10218	fractured.
...	.....	.....
20	12228	crushed.

Results of experiments on stone from North Wales and other places. Specimens Nos. 12, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26.

No. of Speci-men.	Description of Stone.	Locality.	Size.	Weight with which it fractured, in lbs.	Weight with which it crushed, in lbs.	Pressure required to crush a 2in. cube, in lbs.
12	Grauwacke.	Penmaenmawr ...	2in. cube.	40692	67572	67572
14	Granite.....	Mount Sorrel	,,	51444	51444	51444
17	Syenite.....	,, ,, ...	,,	47284	47284	47284
18	Granite.....	Bonaw, Inverary..	1½in.cube	17396	24564	43669
19	,,	Furnace, ,,	,,	24564	24564	43669
20	,,	(A)	,,	22772	24564	43669
21	Limestone..	(B)	,,	17396	19188	34112
22	,,	(C)	,,	18292	19188	34112
23	,,	Anston.....	1in. cube.	2154	3050	12200
24	,,	Worksop	,,	3946	7098	28392
25	Sandstone..	... ...	,,	3050	3498	13992
26	,,	... ...	2in. cube.	10218	12228	12228

The Welsh specimen of grauwacke, from Penmaenmawr, exhibits great powers of resistance, nearly double that of some of the Yorkshire sandstones, and about one-third in excess of the granites, excepting only the granite from Mount Sorrel, which is to the Welsh grauwacke, as ·757 : 1. Some others, such as the Ingleton grauwacke, supported more than the granites, but are deficient when compared with that from Penmaenmawr. The specimen No. 23 is the stone of which the Houses of Parliament are built. Specimens Nos. 25 and 26 were broken to show experimentally the ratio of the powers of resistance as the size is changed. The results are sufficiently near to prove that the crushing weights are as the areas of the surface subjected to pressure.

The specific gravity and porosity of the different kinds of rock vary greatly, and Mr. Shaw, in his desire to obtain the best quality of Yorkshire paving stone, had those from the neighbourhood of Bradford carefully tested in regard to their powers of absorption; the experiments, which were conducted with great precision, gave the following results.

Experiments to ascertain the amount of water absorbed by various kinds of stone.

No. of Specimen.	Description of Stone.	Locality.	Weight before immersion.	Weight after immersion for 48 hours.	Difference of Weight.	Proportion absorbed.
			lbs.			
1	Sandstone..	Shipley	5.4687	5.5546	.0859	1 in 63.6
2	„	Heaton.....	5.2578	5.3632	.1054	1 in 49.8
3	„	Heaton Park.	5.1718	5.2896	.1171	1 in 44.1
4	„	Spinkwell	5.2968	5.4726	.1758	1 in 30.1
5	„	Idle Quarry.	5.7178	5.8203	.1016	1 in 56.3
6	„	Jegrum's-lane	5.5976	5.7187	.1211	1 in 46.2
7	„	Spinkwell	5.6757	5.7851	.1094	1 in 53.8
8	„	Coppy Quarry.....	5 5703	5.6914	.1211	1 in 46.0
9	„	Old Whatley..	5.4726	5.6132	.1406	1 in 38.9
10	„	Manningham-lane.	5.4882	5.6093	.1211	1 in 46.3
11	„	„ „	5.6289	5.7539	.1250	1 in 45.0
12	Grauwacke.	Wales	6.4101	6.4140	.0039	1 in 1641.0
13	Granite.....	Mount Sorrel	5.6875	5.6992	.0117	1 in 485.0
14	„	„ „	5.8007	5.8124	.0117	1 in 495.0
15	Grauwacke.	Ingleton.	5.7500	5.7539	.0039	1 in 1962.6

From the above table it will be observed that specimen No. 15, the Ingleton grauwacke, is the least absorbent, and No. 12, the Welsh grauwacke, absorbs almost as little, while Nos. 9 and 14 of the sandstones absorb most. The granites, though closely granulated, take up much more water than the grauwackes, but less than the sandstones. The resistance of the grauwacke specimens to the admission of water is four times that of the granite, and thirty-six times that of sandstone, such as is found in the Yorkshire quarries.

No. of Specimen	Description of Stone.	Locality.	Size.	Specific gravity.	Pressure to fracture specimen.	Pressure to crush specimen.	Pressure per square inch to crush specimen.	Cubic feet in a ton.	Ratios of powers of absorption.
			cube		lbs.	lbs.	lbs.		1 in
1	Sandstone.	Shipley*.....	2in.	2.452	33524	38900	9725	14.616	63.6
2	,,	Heaton*.....	,,	2.420	33524	40692	10173	14.809	49.8
3	,,	Heaton Park*..	,,	2.385	29940	31732	7933	15.027	44.1
4	,,	Spinkwell	,,	2.329	defective.		....	15.388	30.1
5	,,	Idle Quarry†....	,,	2.464	42484	43380	10845	14.545	56.3
6	,,	Jegrum's-lane†..	,,	2.400	45172	47860	11965	14.933	46.2
7	,,	Spinkwell†	,,	2.456	31732	37108	9277	14.592	53.8
8	,,	Coppy Quarry†..	,,	2.408	37108	41588	10397	14.833	46.0
9	,,	Old Whatley*...	,,	2.415	35316	35316	8829	14.840	38.9
10	,,	Manning'm-lane*	,,	2.401	28148	37108	9277	14.927	46.3
11	,,	,, ,,	,,	2.421	fai	led.	....	14.804	45.0
12	Grauwacke	Penmaenmawr ..	,,	2.748	40692	67572	16893	13.042	1641.0
13	Granite ..	Mount Sorrel ...	,,	2.657	....	....	....	13.489	485.3
14	,,	,, ,, ...	,,	2.675	51444	51444	12861	13.398	495.0
15	Grauwacke	Ingleton	,,	2.787	35316	(53236)	not crd	12.866	1962.6
16	Granite ..	Aberdeen	,,	—	27546	(28340)	not crd	—	—
17	Syenite ..	Mount Sorrell...	,,	—	47284	47284	11821	—	—
18	Granite ..	Bonaw.....	1½in	—	17396	24564	10917	—	—
19	,,	Furnace	,,	—	24564	24564	10917	—	—
20	,,	A	,,	—	22772	24564	10917	—	—
21	Limestone.	B	,,	—	17396	19188	8528	—	—
22	,,	C	,,	—	18292	19188	8528	—	—
23	,,	Anston.....	1in.	—	2154	3050	3050	—	—
24	,,	Worksop	,,	—	3946	7098	7098	—	—
25	Sandstone.	D	,,	—	3050	3498	3498	—	—
26	,,	E	2in.	—	10218	12228	3057	—	—

On comparing the results of the experiments on the Yorkshire sandstones, it will be seen that the difference of resistance to pressure does not arise so much from the variable character of the stone in different quarries, as from the position in which it is placed as regards its laminated surface, the difference being as 10:8 in favour of the stone being crushed upon its bed to the same when crushed in the line of cleavage; the same may be said of the limestones.

Comparing the strengths indicated by the above experiments, I find a very close approximation in the granites, but considerable difference in the Yorkshire sandstones. Mr. Rennie obtained his specimens from the same district, the valley of the Aire; but the force required to crush the Brom-

* Pressure applied in the direction of the cleavage.
† Pressure applied perpendicularly on the bed of the stone.

ley Fall stone was much less than that required to fracture similar specimens from the Shipley quarries. The following table gives some useful results for comparison.

Description of Material.	Crushing force in lbs. per square inch.	Authority.
Porphyry	40416	Gauthey.
Granite, Aberdeen	11209	Rennie.
„ mean of 3 varieties	11564	Experiments 14, 18, 19.
Sandstone, Yorkshire	6127	Rennie.
„ „ mean of 9...	9824	Experiments 1 to 9.
Brick, hard..	1888	Rennie.
„ red	805	Rennie.

From the above it is evident that there is a considerable difference between the results of Mr. Rennie's experiments and those in the preceding tables. This may, perhaps, be due to the different methods pursued in the experiments, or from taking the first appearance of fracture as the ultimate power of resistance. Whereas, there is in some cases a difference of nearly a third between the weight required to produce the first crack, and that required subsequently to crush the specimen. This is the more remarkable as all the specimens did not appear to follow the same law, as in some the weight which fractured the specimen by a continuation of the process ultimately crushed it. Experiments of this kind require close observation, and the reason just given may probably account for the difference between Mr. Rennie's and my own results.

All information respecting the strength of materials must be derived from direct experiment, which is always the safest and best guide; and fully aware of the importance of this fact, I have deemed it expedient to append the following list of the bearing powers of some other materials employed in building, and to which reference may be made in any case where the load is excessive, or where the material is subjected to severe strain.

The necessity of these experiments was the more apparent some years since, in the construction of the Britannia and

Conway tubular bridges, when fears were entertained of the security of the masonry to support, upon the given area, the immense weight of the tubes, upwards of 1,500 tons, resting on one side of the tower. To ascertain how far the material (Anglesea limestone) was calculated to sustain this load, the following experiments were instituted by Mr. Latimer Clarke.

"*Results of experiments made with actual weight on the materials used in the Britannia bridge, January,* 1848.

BRICKWORK.

	lbs. per square inch.
No. 1.—9in. cube of cemented brickwork (Nowell and Co.), No. 1 (or best quality) weighing 54 lbs., set between deal boards. Crushed with 19 tons 18 cwt. 2 qrs. 22 lbs.	= 551.3
No. 2.—9in. cube of brickwork, No. 1 weighing 53 lbs., set in cement. Crushed with 22 tons 3 cwt. 0 qr. 17 lbs.	= 612.7
No. 3.—9in. cube of brickwork, No. 3 weighing 52 lbs., set in cement. Crushed with 16 tons 8 cwt. 2 qrs. 8 lbs.	= 454.3
No. 4.—9¼in. brickwork, No. 4 weighing 55½ lbs., set in cement. Crushed with 21 tons 14 cwt. 1 qr. 17 lbs.	= 568.5
No. 5.—9in. brickwork, No. 4 weighing 54¼ lbs., set between boards. Crushed with 15 tons 2 cwt. 0 qr. 12 lbs.	= 417.
Mean	521.

Note.—The last three cubes of common brick continued to support the weight, although cracked in all directions; they fell to pieces when the load was removed. All the brickwork began to show irregular cracks a considerable time before it gave way.

The average weight supported by these bricks was 33.5

tons per square foot, equal to a column 583.69 feet high, of such brickwork.

SANDSTONE.

	lbs. per square inch.
No. 6.—3in. cube red sandstone, weighing 1 lb. 14⅜ oz., set between boards (made quite dry by being kept in an inhabited room). Crushed with 8 tons 4 cwt. 0 qr. 19 lbs.....	= 2043.
No. 7.—3in. cube sandstone, weighing 1 lb. 14 ozs., set in cement (moderately damp). Crushed with 5 tons 3 cwt. 1 qr. 1 lb.....	= 1285.
No. 8.—3in. sandstone, weighing 1 lb. 15½ ozs., set in cement (made very wet). Crushed with 4 tons 7 cwt. 0 qr. 21 lbs.....	= 1085.
No. 9.—6in. cube sandstone, weighing 18 lbs., set in cement. Crushed with 63 tons 1 cwt. 2 qrs. 6 lbs.	= 3924.8
No. 10.—9¼in. cube sandstone, weighing 58½ lbs., set in cement (77½ tons were placed upon this without effect, = 2042 lbs. per square inch, which was as much as the machine would carry)	
Mean.....	2185.

All the sandstones gave way *suddenly*, and without any previous cracking or warning. The 3in. cubes appeared of ordinary description; the 6in. was fine grained, and appeared tough and of superior quality. After fracture the upper part generally retained the form of an inverted square pyramid about 2½in. high and very symmetrical, the sides bulging away in pieces all round. The average weight of this material was 130 lbs. 10 ozs. per cube foot, or 17 feet per ton.

The average weight required to crush this sandstone is 134 tons per square foot, equal to a column 2351 feet high of such sandstone.

LIMESTONE.

lbs per square inch.

No. 11.—3in. cube Anglesea limestone, weighing 2 lbs. 10 ozs., set between boards. Crushed with 26 tons 11 cwt. 3 qrs. 9 lbs. .... = 6618.

This stone formed numerous cracks and splinters all round, and was considered crushed; but on removing the weight about two-thirds of its area were found uninjured.

No. 12.—3in. limestone, weighing 2 lbs. 9 ozs., set between deal boards. Crushed with 32 tons 6 cwt. 0 qr. 1 lb..... = 8039.

This stone also began to splinter externally with 25 tons (or 6220 lbs. per square inch), but ultimately bore as above.

No. 13.—3in. limestone, weighing 2 lbs. 9 ozs., set in deal boards. Crushed with 30 tons 18 cwt. 3 qrs. 24 lbs. ..... = 7702.6

No. 14.—Three separate 1in. cubes limestone, weighing 2 lbs. 9 ozs., set in deal boards. Crushed with 9 tons 7 cwt. 1 qr. 14 lbs. ..... = 6995.3

All crushed simultaneously.

Mean..... 7579.

All the limestones formed *perpendicular* cracks and splinters a long time before they crushed.

Weight of the material from above = 165 lbs. 5 ozs. per cubic foot, or 13½ feet per ton.

The weight required to crush this limestone is 471.15 tons per square foot, equal to a column 6433 feet high of such material."

Previously to the experiments just recorded, it was deemed advisable not to trust to the resisting powers of the material of which the towers of either bridge were composed; and, to make security doubly sure, it was ultimately arranged to rest

the tubes upon horizontal and transverse beams of great strength, and by increasing the area subject to compression, the splitting or crushing of the masonry might be prevented. This was done with great care, and the result is the present stability of those important structures.

In conclusion, I have now to submit to the consideration of the society and the practical builder the following general summary of results, obtained from various materials, showing their respective powers of resistance to forces tending to crush them.

GENERAL SUMMARY OF RESULTS ON COMPRESSION.

	Description of Material.	Crushing force in lbs. per square inch.	Authority.
Iron and Steel.	Cast steel		
	Blister steel		
	Cast iron (white, derived from 14 meltings)	214816	Fairbairn's Experiments on the Mechanical Properties of Metals.—Transactions of the British Association, 1854.
	Ditto (from 12 meltings)	163744	
	Ditto (from ordinary castings)	89600	
Stone.	Porphyry	40416	Gauthey.
	Grauwacke, Penmaenmawr	16893	Exprmts. No. 12.
	Granite, mean of 3	11565	Do. Nos. 14, 18, 19.
	Sandstone, Yorkshire	6127	Rennie.
	Ditto, mean of 9 exprts.	9824	Exprmts. 1 to 10.
	Ditto, Runcorn	2185	Clark.
	Limestone	8528	Exprmts. 21, 22.
	Ditto, Anglesey	7579	Clark.
	Ditto, Magnesian—mean.	5074	Exprmts. 23, 24.
	Brick, hard	1888	Rennie.
	Ditto, red	805	,,
	Ditto, mean of 4 exprts.	1424	Clark.
Timber.	Box	9771	Hodgkinson.
	English Oak (dried)	9509	
	Ash (ditto)	9363	
	Plumtree (ditto)	8241	
	Beech	6402	
	Red Deal	5748	
	Cedar	5674	
	Yellow Pine	5375	

It is observed by Professor Hodgkinson, in his experiments on timber, that great discrepancies occurred when the woods were in different degrees of dryness; wet timber, though felled for a considerable time, bearing in some instances less than one-half what it bore when dry.

Professor Hodgkinson has also experimented on round and square columns of sandstone from Ped Delph, Littleborough, Lancashire, a much harder stone than that found on the banks of the Aire. With regard to these experiments, it appears "that there is a falling off in strength in all columns from the shortest to the longest, but that the diminution is so small, when the height of the column is not greater than about twelve times the side of its square, that the strength may be considered uniform, the mean being 10,000 lbs. per square inch or upwards.

"From the experiments on the columns 1in. square, it appears that when the height is fifteen times the side of the square, the strength is slightly reduced; when the height is twenty-four times the height of the base, the falling off is from 138 to 96 nearly; when it is thirty times the base, the strength is reduced from 138 to 75; and when it is forty times the base, the strength is reduced to 52, or to little more than one-third. These numbers will be modified to some extent by experiments now in progress.

"As long columns always give way first at the ends, showing that part to be weakest, we might economize the material by making the areas of the ends greater than that of the middle, increasing the strength from the middle both ways towards the ends. If the areas of the ends be to the area of the middle, as the strength of a short column is to that of a long one, we should have for a column, whose height was twenty-four times the breadth, the areas of the ends and middle as 13766 to 9595 nearly. This, however, would make the ends somewhat too strong,

since the weakness of the long columns arises from their flexure.

"Another mode of increasing the strength would be that of preventing flexure, by increasing the dimensions of the middle.

"From the experiments it would appear that the Grecian columns, which seldom had their length more than about ten times the diameter, were nearly of the form capable of bearing the greatest weight when their shafts were uniform, and that columns tapering from the bottom to the top were only capable of bearing weights due to the smallest part of their section, though the larger end might serve to prevent lateral thrusts. This latter remark applies, too, to the Egyptian columns, the strength of the column being only that of the smallest part of the section.

"From the two series of experiments, it appeared that the strength of a short column was nearly in proportion to the area of the section, though the strength of a larger one is somewhat less than in that proportion."

I give these extracts from Mr. Hodgkinson's paper, to show the advantages to be derived from proper attention to the construction of columns, not only as regards their resistance to a crushing force, but as to the propriety of enlarging the ends to increase their powers of resistance.

Experimental data cannot always be applied in architectural constructions; but it is, nevertheless, essential that the architect and builder should be cognizant of the facts, in order that they may prepare their plans, as far as possible, in accordance with them, and effect the greatest amount of work with the least waste of material.

The accompanying plate exhibits the appearance of some of the fractured specimens; in all, it will be observed, that there is a tendency to give way by one or more wedges forcing out from the sides in all directions.

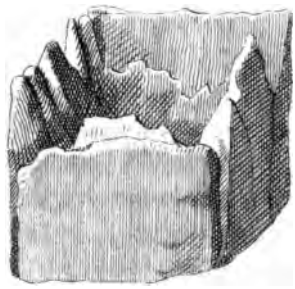
The plate shows the fractured appearance of,

Specimen No.	1.	Sandstone, Shipley, Bradford.
,,	2.	,, Heaton, Bradford.
,,	3.	,, Heaton Park, Bradford.
,,	5.	,, Idle Quarry.
,,	7.	,, Spinkwell.
,,	12.	Grauwacke, Penmaenmawr, Wales.
,,	14.	Granite, Mount Sorrel.
,,	20.	,, A.
,,	21.	Limestone, B.
,,	22.	,, C.
,,	23.	,, Anston.
,,	25.	Sandstone, D.
,,	26.	,, E.

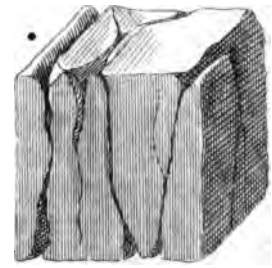
The other specimens operated upon were not sufficiently defined in the line of fracture to admit of their form being sketched; most of them having been crushed almost to powder.

Specimen N.° 1

Specimen N.° 2

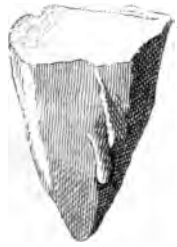


Shipley



Heaton

Specimen N.° 3



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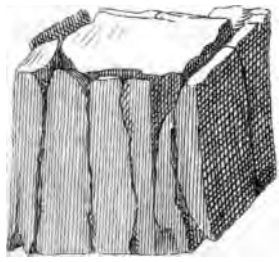
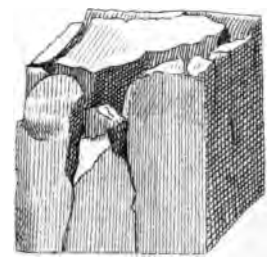


Heaton Park



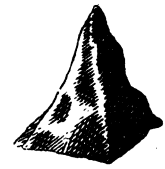
Tolle Quarry

Holmes, Hull. Doyle & Mann.

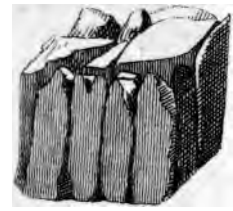
Specimen No. 7

Spinkwell

Specimen No. 20



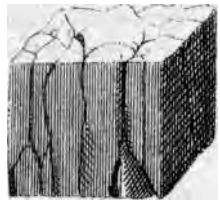
A



Granite

Specimen No. 21

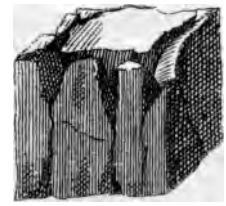
B



Limestone

Specimen No. 22

C

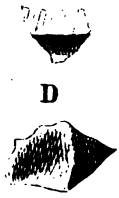


Limestone

No. 23

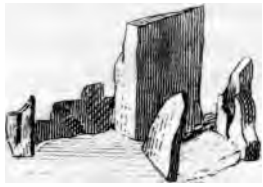
Limestone
Anston

D

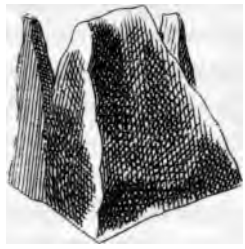


Sandstone
No. 25
1 Cube

No. 12
Grauwacke

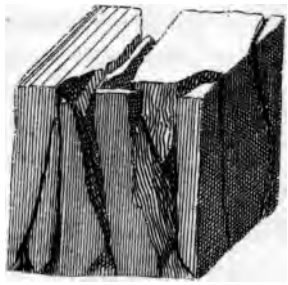


Full Size
Specimen No. 14
Mount Sorrel Granite



E

Full Size



Sandstone No. 26
2 Cube

IV.—*On the Fusion of Metals by Voltaic Electricity.*

By J. P. Joule, F.R.S., &c.

[*Read March 4th*, 1856.]

The attention of practical scientific men has of late been much occupied with the question, how far it is possible to forge large masses of iron, without destroying the tenacity and other valuable qualities of the metal employed. In welding iron, the metal is raised to the high temperature at which it assumes a soft and incipient viscid consistency. Two pieces of iron in this condition will adhere together slightly, if merely placed in contact with one another. That a firm junction cannot be made in this way is simply owing to the fact that few particles are brought into contact, and that the metallic continuity is only established at those points. The hammer is, therefore, employed to cause the entire surfaces to meet together. The same end has also been attained by the employment of great pressure; and probably we shall ultimately see large masses of forged iron formed by simply subjecting a bundle of smaller pieces, raised to the welding temperature, to the operation of great pressure. To succeed in the latter process, it would however be requisite to press clean unoxidized surfaces together. Indeed the importance of presenting clean surfaces together in ordinary welding cannot be too strongly insisted on; for, if oxide of iron be present, a portion of it will not fail to remain at, or in

the neighbourhood of, the juncture, and seriously impair the quality of the iron at those points.

It occurred to me some months ago that it might be possible to employ the calorific agency of the electric current in the working of metals. By the use of a voltaic battery there appeared to be no doubt but that small pieces of metal could be fused into one lump. If so, it was obvious that by employing a battery of adequate size the largest masses of wrought iron could be produced, the question resolving itself simply into one of cost. It was not before the last month that I had an opportunity of witnessing an experiment on a small scale. It was performed in the laboratory of Professor Thomson. He surrounded a bundle of iron wires with charcoal, and, after transmitting a powerful current through it for some time, the wires were found in one part to be completely fused together.

More recently I have made several experiments in which the wires were placed in glass tubes, surrounded with charcoal, &c. With a battery of six Daniell's cells I have thus succeeded in fusing several steel wires into one, uniting steel wires with brass, platina with iron, &c. I doubt not but that in many instances the process would advantageously supersede that of soldering, especially when, for thermo-electric or other purposes, it is desirable to join metals of difficult fusibility without the intervention of another metal which melts at a lower temperature.

Having demonstrated the possibility of obtaining perfect junctions by means of the voltaic current, let us inquire what expenditure of battery materials would be necessarily involved. In the outset it may be remarked that were not heat continually removed, by conduction, convection, and radiation, from a wire carrying a current of however low a degree of intensity, the wire would ultimately attain an excessively high temperature on account of the continuous augmentation

of heat within it. Now the escape of heat may be largely prevented by means of non-conducting substances, and will be nearly proportional to the surfaces, so that by employing sufficiently large masses of metal, and surrounding them with non-conducting materials, it may be reduced to almost any extent. The quantity of zinc required to fuse a large mass of iron may therefore be estimated as follows.—

I have shown in a paper already communicated to the Society, that the quantity of heat due to the intensity of a Daniell's cell is 6°.129 per pound of water for every 33 grains of zinc dissolved.* In working with a voltaic battery, it is generally an advantageous arrangement to make the resistance of the battery one-half that of the entire circuit. Hence, as the quantity of heat evolved in any part of the circuit is proportional to its resistance, we may take half the above, or 3°.064 per pound of water, as the heat which may be advantageously produced outside a Daniell's battery by the dissolution of 33 grains of zinc. Calling the temperature of incipient fusion of iron 4,000° above the ordinary temperature of the atmosphere and the specific heat of iron 0.11, we find 4,740 grains of zinc to be the quantity consumed in the voltaic battery, in order to raise one pound of iron to the temperature of fusion. But as a considerable quantity of heat will be rendered "latent," 5,000 grains may be taken as the estimate of minimum consumption of zinc, in a Daniell's battery, in order to effect the fusion of one pound of iron.

The same effect is due to the heat evolved by the combustion of 500 grains of coal, but on account of the large quantity of heat which must necessarily escape up the chimney of a hot furnace, we may estimate the minimum actual consumption at 1,000 grains.

The quantity of zinc consumed in the voltaic process is therefore nearly equal to that of the iron to be melted, but it would

* Memoirs of the Literary and Philosophical Society, Vol. vii., p. 94.

be possible to effect the same object in a more economical manner, by availing ourselves of the use of the magneto-electrical machine. This machine enables us to obtain heat from ordinary mechanical force, which mechanical force may again be derived from the conversion of heat, as in the steam engine. In a steam engine it is practically possible to convert at least one-fifth of the heat due to the combustion of coal into force, and one-half of this force applied to work a magneto-electrical machine may be evolved in the shape of heat. Hence then it is possible to arrange machinery so as to produce currents of electricity which shall evolve one-tenth of the quantity of heat due to the combustion of the coal employed. So that 5,000 grains of coal used in this way would suffice for the fusion of one pound of iron.

V.—*A Short Account of the Life and Writings of the late Mr. William Sturgeon.*

By J. P. Joule, V.P., F.R.S., Hon. Mem. Phil. Soc. Cambridge, Corr. Mem. R.A. Turin, &c.

[*Read October 7th*, 1856.]

A pardonable vanity of our human nature makes us seek into the past, in order to connect the names of those we respect and love, with the great and good of ancient times. In so doing we award to our contemporaries a portion of the praise and admiration which are due to their eminent forefathers. But the search is often unprofitable, and many of our greatest men, descended from an obscure or unknown parentage, have been the first to render the family name illustrious. Of such was the subject of the present memoir, who was born in 1783, at Whittington, a village in the county of Lancaster, near the border which divides it from Westmoreland. His father was John Sturgeon, a shoemaker, who came from the neighbourhood of Dumfries, and married Betsy Adcock, daughter of a small shopkeeper in Whittington. The offspring of this marriage were William, Margaret, and Mary. Of these, Mary died in infancy; and Margaret married John Coates, and died the mother of a numerous family.*

John Sturgeon appears to have been a man who paid more attention to fishing for salmon in the river Lune, a pursuit in

* The youngest of these, Ellen, who was only a few weeks old at the time of her mother's death, was on that event kindly taken into the family of her uncle, William Sturgeon, and ever afterwards treated as his own daughter.

which he gained much local celebrity, than to his legitimate business. Young William at a tender age was nightly compelled, with a torch in his hand, to wade up to his middle in the water, while his father stood ready to spear such fish as were attracted by the glare. The treatment he experienced during the day was equally harsh, and he was liable to severe chastisement whenever his strength proved unequal to labours which would have been unsuited to a child of double his age. It argues strongly for his domestic virtues and filial piety that in after years the happiness of this parent, to whom he owed so little, was the object of his constant solicitude. Nor were these efforts lost. His father's old age bore the fruits of virtue and religion.

At ten he had the misfortune to lose his mother, an estimable woman, upon whom, in consequence of the habits of his father, the support of the family mainly depended. Apprenticed, at the age of thirteen, to a shoemaker at Old Hutton, a village near Kirby Lonsdale, he was doomed to be even more cruelly treated than at home. The ill usage of apprentices was very common at that time, and the perpetrators of it too frequently escaped with impunity. Not content with exacting a slavish drudgery on the week day, this man compelled Sturgeon on the Sunday to carry game cocks from one part of the country to another, so as, in the language of that ancient but detestable sport, to change their walks. He also used much violence, and starved his apprentices to such a degree that they were obliged to make free with the hares and rabbits of the neighbourhood in order to supply their hunger. So long as Sturgeon was a mere child he patiently submitted to this tyranny, but when at the age of sixteen he felt strong enough to resist force by force, he apprised his master of that circumstance, who, with the low cunning and cowardice suitable to such a character, ever afterwards observed a more conciliatory deportment.

It seems almost incredible that, amid such hardships and surrounded by such vicious examples, Sturgeon could have acquired anything valuable beyond mere proficiency in his trade, or that he could even have resisted the temptation to follow evil courses so constantly held out. But it, nevertheless, appears that he contrived to acquire some proficiency in music, and the knowledge of several mechanical arts. His ability in the exercise of one of the latter may be judged by the following anecdote, which will illustrate at the same time the energy of character which became so conspicuous in after life. One of the celebrations of the Guild at Preston took place during his apprenticeship, and William Sturgeon and his fellow-apprentice having heard much talk about it, determined to go and see it. Their master they well knew would not give his consent, but this difficulty they got over by the simple expedient of starting on their trip without asking it. Another and more serious difficulty arose from the awkward circumstance of neither of them possessing any money. Sturgeon, who had shown some talent in cleaning clocks and watches during his residence at Hutton, contrived not only to support himself and fellow-apprentice during their journey to and from Preston by what he obtained from clock cleaning by the way, but even to arrive at home with money in pocket. On their return from satisfying their curiosity at Preston Guild, the apprentices had to undergo the ordeal of a sound thrashing from their brutal master.

Dissatisfied with his position as a journeyman shoemaker, and seeing little prospect of improving his condition at Kirby Lonsdale, he, in 1802, enlisted in the Westmoreland Militia, and two years afterwards volunteered as a private into the 2nd Battalion of Royal Artillery. Soon after entering this corps he married Mary Hutton, a widow, who kept a shoe shop at Woolwich. The issue of this marriage was two daughters and a son, namely, John and Elizabeth, twins, and Ann, all of whom died in their infancy. After the death of

his first wife he married, in 1829, Mary Bromley, of Shrewsbury, by whom he had a daughter, who died in infancy.

Being called into foreign service soon after his marriage with his first wife, he made the first systematic efforts for the improvement of his mind. While in Newfoundland he was first directed to the contemplation of electrical phenomena, on the occasion of a terrific thunderstorm. His interest in the works of nature being thus excited, he prepared himself for their study, by teaching himself reading and writing and the elements of grammar. A sergeant in the artillery possessed a tolerable library of books, to which the generous owner gave him constant access. It was his practice when he came off guard at night to take from his knapsack the book and candle he generally carried there, and to spend that time in reading which by the other soldiers was devoted to repose. He was thus able to devote a considerable time to mathematics, and to the study of the dead and living languages. To these he added optics, and various other branches of natural philosophy. He also found time to acquire various mechanical arts, such as that of lithography, in which he attained afterwards considerable proficiency.

Notwithstanding his love of these pursuits he did not neglect, while in the army, his trade as a shoemaker, and the excellence of his workmanship caused him to be employed in this capacity by most of the officers of the corps. After leaving the army he followed this avocation in Lancaster, until, at the instance of his wife, whose relations resided at Woolwich, he returned thither, and began to prosecute with renewed assiduity his favourite intellectual studies.

The difficulties he encountered in his strivings after scientific truth at this time, will be best understood by quoting his own words from a manuscript I have by me. He says:—"After leaving the service of the Royal Artillery in 1820, and as my slender finances presented opportunities, I turned my attention to scientific inquiries, and to the construction of some of those

philosophical apparatus which, from my boyhood, I had been an admirer of, but which, during *my* services at least, a military profession precluded all further knowledge of than that which was to be derived from books of science; a species of commodity at that time exceedingly rare in the army, even in the distinguished branch to which I had the honor to belong. Fortunately for the service, every encouragement is now given for mental improvement both in the army and navy. Having spent the prime of life in the service, during a period of the most rigorous military discipline that ever occurred to the British army, I can vouch from experience that the value of a soldier is not likely to be deteriorated by mental cultivation; nor do I think it possible that any soldier could be more devoted to his profession, than he who improves his mind by scientific studies. The more science is cultivated in the service the more efficient will be its members in the performance of their respective duties, and consequently the more formidable will they be found when those duties are required against a well disciplined army."

"My first step towards constructing apparatus was the purchase of an old lathe, and a few tools to work with. My stock of tools, however, was very limited, from a want of means to purchase more; so that many rude substitutes had frequently to be brought into requisition. And as I had no practice either at the lathe or the vice, my first essays in apparatus making were necessarily deficient of those elegancies of structure and refinements of workmanship, which always characterize the productions of regular-bred instrument makers."

"Notwithstanding these disadvantages, however, *hope* and perseverance surmounted every difficulty that was met with, and I soon found myself capable of constructing such pieces of apparatus as I immediately wanted for my own purpose; and it was not long before I found purchasers for others, even amongst the first-rate instrument makers in London. I am

not aware that my progress was due to any particular genius that I possessed, although I never had even a moment's instruction from any person; and I record these particulars with no other view than that of encouraging others to persevere, who may have similar disadvantages to encounter."

"Having become acquainted with Mr. Thomas Rose, a gentleman of considerable scientific attainments, and at that time (1823) residing in Woolwich, I had the good fortune to become possessed of an electrical machine, much earlier than I had expected. Mr. Rose being about to construct a machine of this kind for his own use, presented me with the materials he had prepared for it as soon as he became aware that I was in want of one. By the liberality of this gentleman, I had thus placed in my hands a glass cylinder ten inches in diameter, and an excellent mahogany frame for its support. Both parts were quite new, but the cylinder was not mounted, nor was it furnished with caps at its necks. Although the fitting up of this machine and its appendages cost a considerable portion of time, I was amply rewarded by its happening to be an excellent *working* apparatus, which I used in my lectures and investigations for several years afterwards."

As above intimated, Mr. Sturgeon procured his discharge from military duty in 1820, his conduct while a soldier having been, according to the testimony of his commanding officer, Major Jones, "altogether unimpeachable," and was thus enabled to devote himself with greater assiduity to the pursuit of his favorite studies. At that period scientific research had just received a great impulse from the discovery by Oersted, that a current of voltaic electricity passing through a conducting wire, is capable of deflecting a poized magnetic needle from its position in the magnetic meridian of the earth. This most remarkable discovery, by which the sciences of electricity and magnetism were permanently allied, created an intense interest, and accordingly we find that the most eminent natural philosophers of the day immediately entered upon the

new field of investigation thereby opened. Davy and Arago magnetized steel needles, by placing them in the vicinity of a wire carrying a voltaic current. Ampère found that two parallel wires conveying currents in the same direction attracted one another, but that they repelled one another if the electricity travelled in contrary directions; and Faraday produced the revolution of a magnetic bar round a conducting wire, as well as the reverse phenomenon of the revolution of a conducting wire round one of the poles of a magnet.

Mr. Sturgeon followed in the same track, and the mechanical skill he possessed enabled him to construct and improve the beautiful revolving apparatus, which had been devised by Faraday, Barlow, Ampère, and others. The rotations are in all cases owing to the action of a wire carrying a current of electricity, upon either a permanent magnet or another electro-dynamic wire, and may in every case be traced to Oersted's law. Considerable instruction may, however, be derived from their study, and it would appear that they were the object of Mr. Sturgeon's earliest scientific efforts. We accordingly find in the *London Philosophical Magazine* for September, 1823, an account of his modification of Ampère's rotating cylinders. This contrivance is succinctly described by Mr. Jones, optician, as "consisting of two sets of revolving cylinders, one suspended on each pole of an inverted horse-shoe magnet. Upon the insertion of dilute nitric acid the two sets of cylinders simultaneously enter into rotations, in a very interesting and striking manner." The effect, adds the same authority, is the most pleasing I have ever seen.

In 1824 Mr. Sturgeon published four papers on thermo-electricity, in which he succeeded in giving a fresh proof of the complete analogy which subsists between thermo-electric and voltaic currents.

In 1825 he presented to the Society of Arts the *complete set of novel electro-magnetic apparatus*, which is described in their transactions. The great merit of this collection con-

sisted in the improved adaptation of the batteries, magnets, &c. to one another, by means of which he was enabled to perform with a galvanic arrangement, no larger than a pint pot, experiments which had previously required the use of a cumbrous and costly battery. A principal improvement was effected by increasing the size and power of the magnet, Mr. Sturgeon having had the sagacity to observe that the intensity of the action was more advantageously augmented by an increase of the magnetic force, than by an enlargement of the size of the conductors of electricity, whereby the friction on the pivots of the revolving apparatus would have been made too sensible. The Society of Arts testified its sense of the importance of this contribution, by awarding to its author its large silver medal, with a purse of thirty guineas.

The most important piece of apparatus in the above collection was a bent bar of iron, surrounded with a coil of conducting wire. It was the earliest contrivance for showing the extraordinary and instantaneous inductive effect of a voltaic current on soft iron. I have already adverted to the magnetization of steel needles by Arago and Davy, but it appears that Mr. Sturgeon was the first who observed the wonderful facility with which soft iron can be made intensely magnetic by the galvanic current, as well as the extreme rapidity of the action. Mr. Sturgeon appears to have discovered the soft iron electromagnet, and to have constructed it both in the straight and horse-shoe shape as early as 1823. The soft iron electromagnet has been since introduced into most electric telegraphs.

A paper published in the *Philosophical Magazine* for June, 1826, contains a discussion of the cause of difficulty of firing gunpowder by electrical discharges. Mr. Sturgeon showed that in order to succeed, it was necessary to place a body of low conductive power in the circuit, such as a piece of wet thread. The violence of the discharge was by this means so much diminished, that the electric fluid from eight feet of

coated glass produced no sensible shock when passed through the body, a burning sensation only being experienced. He remarks, that "by employing either a moistened thread, or narrow tube of water, gunpowder may be ignited at several interruptions of the same circuit. I have frequently passed the fluid through my own body and fired six guns by one discharge of a jar, and so instantaneous is the ignition at the several guns, that their united reports appear like the report of one gun only."

In 1830, Mr. Sturgeon published a pamphlet, entitled, "Experimental Researches in Electro-Magnetism, Galvanism," &c., embracing an extensive series of experiments, chiefly in relation to the structure and action of galvanic batteries and the dry electric column.* It contains the record of a variety of observations, proving that the strongest chemical action on the positive plates was not always accompanied by the transmission of the most powerful currents of electricity. Mr. Sturgeon considered these experiments to militate against the chemical theory of galvanism; but a more searching investigation would have convinced him that, in the adduced instances, the chemical action was in a great measure occasioned by minute local circuits on the plates. It was reserved for Dr. Faraday, a year afterwards, to establish the chemical theory in an unassailable position, by his great discovery of the definite chemical action of electrical currents. There are, however, some facts in this pamphlet which have led to practical results of very great importance. I allude, first, to the remarkable change produced in the electrical powers of a metal by roughening its surface, such roughening being shown by Sturgeon to render zinc less electro-positive, so much so, that voltaic batteries constructed of no other metals than rolled zinc and cast zinc are "suffi-

* This work is unfortunately only a fragment. The printer died shortly after a portion was finished, leaving his affairs in a disordered state. The MS. of the remainder was consequently lost.

cient for the exhibition of most electro-magnetic experiments." Mr. Sturgeon was prepared to meet with this remarkable fact, having early in 1827 constructed several dry electric columns, in which zinc roughened on one side was the only metal employed. The importance of employing rolled instead of cast zinc for voltaic batteries was thus made evident.

The second fact to which I shall allude, as developed in this pamphlet, is the great advantage to be derived from amalgamating the zinc plates of a voltaic battery. Sir Humphrey Davy, in his Bakerian Lecture for 1826, announced that amalgamated zinc is positive relatively to pure zinc, without, however, drawing any conclusion regarding the construction of voltaic batteries. Mr. Kemp, in 1828, published in Professor Jameson's Journal, the account of a battery in which the positive metal consisted of liquid amalgam of zinc. Mr. Sturgeon appears, however, to have been the first person who introduced the use of amalgamated plates of zinc. After pointing out the method of amalgamating the plates, by first dipping them in a solution of sulphuric acid, and then immersing them in mercury, or spreading mercury over them with a piece of rag, he says, "were it not on account of the brittleness and other inconveniences occasioned by the incorporation of the mercury with the zinc, amalgamation of the surfaces of the zinc plates in galvanic batteries would become an important improvement; for the metal would last much longer, and remain bright for a considerable time, even for several successive hours,—essential considerations in the employment of this apparatus. Notwithstanding the inconveniences, however, the improvement afforded by amalgamating the surfaces of zinc plates becomes available in many experiments; for the violent and intense chemical action which is exercised on zinc by a solution of sulphuric or muriatic acid, with the consequent evolution of heat, and annoying liberation of hydrogen, have no place when the plates are amalgamated; the action is tranquil and uniform,

and the disengagement of gas, which is trifling, occurs only when the circuit is complete, and at the surface of the copper plate. The electric powers are highly exalted, and continue in play much longer than with pure zinc; and the only care of the experimenter is to prevent the copper, or whatever metal be substituted, from becoming amalgamated."

From the earlier portion of the above extract, it has been alleged that Mr. Sturgeon did not fully perceive the practical superiority of amalgamated, over ordinary zinc plates; but generous and even candid criticism will attribute his reserve to his praiseworthy aim to place before the reader the probable disadvantages as well as the real ascertained advantages of his invention. How much the latter predominated over the former, in Mr. Sturgeon's mind, will be obvious to any one who reads the whole passage. I need hardly remark, that amalgamated zinc plates are at the present day employed in Grove's, Daniell's, and, in short, every form of improved battery.

I next notice a memoir on the thermo-magnetism of homogeneous metals, published in the *Philosophical Magazine* for 1831, which contains a very laborious investigation of the effect of local heat on simple metals, by which he confirms Yelin's observation, that currents are produced in any metal by an unequal application of heat, and shows that these currents have a particular reference to the crystalline structure of the metal; bismuth, antimony, and zinc, which in a pure state exhibit the phenomena in an eminent degree, losing it nearly altogether when their crystalline condition has been destroyed by alliage with a small portion of tin or lead. Professor Thomson has recently discovered that *strain*, whether arising from crystalline structure or any other cause, produces, according to certain laws, an alteration both in the thermo-electric character of metals, and their power to conduct electrical currents.

In the year 1825 Arago announced his remarkable dis-

covery of the magnetism of rotation. He showed that a magnetic needle was deflected when a disc, composed of any kind of substance, was revolved near it. This very interesting phenomenon immediately occupied the attention of the most distinguished physicists, among whom the names of Seebeck, Herschel, Babbage, Christie, and Barlow, may be particularly mentioned. Herschel and Babbage remarked that a slit in the revolving plate materially diminished its action on the needle. Mr. Sturgeon took up the subject in 1832, and after much labour came to the conclusion that the effects were probably owing to a disturbance of the electric fluid by magnetic action. The words he uses are, "It would, however, be no great stretch of the imagination to suppose a disturbance of the electric fluid by magnetic action, as it would be only a kind of re-action to that which takes place in electro-magnetism." From the above extract there can be little doubt that Mr. Sturgeon would presently have arrived at the discovery of magnetic electricity, had he not been anticipated by Dr. Faraday, who, in November, 1831, communicated to the Royal Society his paper, "On the Evolution of Electricity from Magnetism," which forms the 2nd section of the first of that inimitable series of experimental researches, which has contributed so greatly to the scientific renown of Britain.

Van Marum and others had shown that a voltaic battery is able to charge coated glass. After repeating their experiments, Mr. Sturgeon constructed an apparatus, by means of which a leyden battery in connection with a series of Cruickshank's voltaic plates is repeatedly charged and discharged, by means of the revolution of a toothed wheel. In this way "the discharges can be made in such rapid succession as to prevent the sensation of distinct shocks, the effect on the animal economy being similar to that produced by a voltaic battery charged with acid and water. No shock was produced independently of the glass battery."

In 1836 Mr. Sturgeon communicated a paper to the Royal Society, which, however, being denied insertion in the *Philosophical Transactions*, received publication in the *Annals of Electricity*, entitled, "Researches in Electro-Dynamics." It contains the description of a machine, in which a coil of wire made to revolve between the poles of a horse-shoe magnet becomes the source of copious electrical currents. Another machine is also described, in which the revolving coil is furnished with a core of iron. Magneto-electrical coil machines had been constructed previously, the most celebrated being those of Pixii and Saxton. In these machines the current reciprocated at every half revolution of the coil, or a stronger current being forced in one direction than in another, the difference only could be utilized. Therefore, though able to exhibit some interesting phenomena, such as the spark and shock, they were almost powerless to produce deflections of the magnetic needle or electro-chemical decompositions. Mr. Sturgeon, by means of a very beautiful arrangement of four semi-wheels, mounted on the axis of his machine, united the entire energies of the opposing currents in one direction. This admirable invention received at his hands a still further improvement, by the introduction of springs pressing against the revolving discs, and the use of oil as a lubricating agent; mercury, which presents many very serious inconveniences, being thus superseded. In fact, the magneto-electrical machine received from Mr. Sturgeon's hands an improvement even more essential than that which the steam engine received from the genius of Watt, and henceforth it could be employed for telegraphic communication, chemical decomposition, and in short all the purposes for which a voltaic battery is available. An opinion is expressed by Mr. Sturgeon that the magneto-electrical machine thus improved, would ultimately entirely supersede the use of the voltaic battery, and I cannot but concur in it for reasons which I have stated fourteen years ago. The argument is simply this. It has been shown by

Liebig, and also demonstrated by my own experiments, that the production of force by the oxidation of zinc, is at least one hundred times as expensive as that derived from the combustion of coal in the steam engine. Therefore, admitting that half the effect is wasted during the conversion of ordinary force into that of current electricity, and also that half the useful effect is wasted in the production of force by the voltaic battery, we arrive at the conclusion that the zinc requisite to produce a current of given intensity is at least twenty-five times as expensive as the coal which, consumed in a steam engine working a Sturgeon's magneto-electrical machine, would be able to effect the same result.

In an inquiry on the "Attributes of the Galvanometer," he found that a voltaic pair, enfeebled by a long continued action, is able to produce a powerful temporary current after a few minutes rest. I have since been able to show that the strong initial current which takes place on the first immersion of a pair of zinc and copper plates into dilute acid is owing to the presence of oxygen on the surface of the negative plate.

In 1832 Mr. Sturgeon constructed an electro-magnetic engine for turning machinery, which was the first contrivance by means of which any considerable mechanical force was developed by the voltaic current. Since that time, engines of various forms have been constructed by Jacobi, Davidson, and others; but, as I have already observed, the hopes once entertained of superseding steam as a motive force were found to be fallacious.

Professor Henry appears to have been the first who observed a spark on the disruption of a voltaic circuit in which a long wire or coil was included. This phenomenon he justly attributed to the dynamical induction discovered by Dr. Faraday. Mr. Jenkin observed that on placing a bar of iron within the coil, the intensity of the electrical action on the breaking of the circuit is sufficient to produce a shock. Henry and Faraday extended the subject still further, by

papers published almost simultaneously in the beginning of 1835. In 1837 Mr. Sturgeon produced his electro-magnetic coil machine, consisting of a coil of thick wire surrounded by a helix of thin wire. The coil of thick wire was in connection with a pair of galvanic plates: an arrangement being made for rapidly making and breaking the circuit. The ends of the helix of thin wire were employed to communicate the shock, which is further enhanced by the insertion into the axis of the coil of a *bundle of iron wires*, or a *scroll of thin sheet iron*. This apparatus is the most efficient ever employed by medical practitioners, and its power is such that "a strong shock and bright spark are produced when the battery employed consists of a copper and zinc wire (No. 15) immersed one-tenth of an inch deep in dilute nitrous acid." Mr. Dancer has made a capital improvement on this instrument, by supplying a self-acting apparatus, consisting of a piece of iron attached to a spring, by the intermittent attraction of which the use of a toothed wheel is dispensed with.

A research concerning the fracture of leyden jars by electrical explosions conducted Mr. Sturgeon to the discovery of the means of preventing such accidents, by connecting the inner coating of the jar with the rod which supports the ball by means of strips of tinfoil. So effectual did Mr. Sturgeon find this simple contrivance to be, that during twelve years he did not break a single jar, although during that period he discharged a battery of twelve jars some hundreds of times from the most intense electrization.

In the autumn of 1838 a series of experiments was performed at the house of Mr. Gassiott, of Clapham-common, with a voltaic battery which was the joint property of Mr. Gassiott and Mr. Mason. These experiments appear to have been conducted by Messrs. Gassiott, Mason, Sturgeon, and Walker. After various interesting results had been obtained, Mr. Sturgeon, who had been previously requested to provide a catalogue of the experiments which it would be

desirable to make, had the opportunity of observing, for the first time, a highly important fact, which he describes in the following words:—"The battery was in series of one hundred and sixty pairs. I brought the tip ends of the polar wires (copper wire, one-tenth of an inch diameter) into contact, end to end, then withdrew them gently and very gradually from each other, keeping the flame in full play between them, till they were separated about one-fourth of an inch. In a few minutes the positive wire got red hot for half an inch, but the negative wire never became red. I repeated this several times in order to be convinced of the fact. I next laid the wires across one another, and brought them into contact about an inch from the extremities, and separated them as before. In a short time the whole of that part of the positive wire from the point of crossing to the extremity became very red hot, but the negative end never got even to a dull redness; it was certainly very hot, but never higher than a black heat. I next increased the length of the ends of the wires exterior to the circuit, and eventually heated two inches of the positive wire to a bright redness, but no such heat took place on the other wire. Thus satisfying myself that I was not mistaken, I called Mr. Mason to come and look at it; and, after satisfying that gentleman by an experiment or two, we called Mr. Gassiott and Mr. Walker to come and witness the novel phenomenon." Mr. Sturgeon considered that the heat was driven along bodily by the electric current, so as to accumulate at the point whence the discharge across the air takes place, an hypothesis which cannot be entertained at the present day. The true explanation of the phenomenon is most probably that advanced by Professor Thomson, viz., that in thermo-electric arrangement air stands in the same ratio to copper as bismuth does to antimony. Whence heat is evolved by electricity passing from copper to air, but cold by the reverse action.

Porrett had discovered a disturbance of the hydrostatic

level by voltaic action. In his experiments, a glass vessel divided into two compartments, by a bladder partition, had one of the partitions filled with water. By sending a voltaic current through the diaphragm the water was carried along with it until nearly the whole of it was driven into the other compartment. Mr. Porrett employed a battery of eighty cells, but Mr. Sturgeon succeeded in obtaining a striking result, of a similar nature, by the use of a simple Daniell's cell, the copper and zinc plates of which were connected together by a conducting wire; after a few days action the solution of sulphate of copper was found to be four inches higher than the level of the liquid in contact with the zinc plate. There is some reason to believe, that in Mr. Sturgeon's experiment, the ordinary phenomenon of endosmose and exosmose, so ably discussed by Professor Graham, had some place. Indeed, Mr. Porrett's experiment is, probably, only a peculiar instance of the mutual action of two dissimilar fluids in a porous material, the one fluid positively electrified, and the other negatively electrified water.

In investigating the action of heat on the poles of a magnet, Mr. Sturgeon found that an alteration of attraction for a suspended needle was thereby produced, which alteration subsided to a considerable extent as the magnet became restored to its original temperature. Mr. Sturgeon drew from his observations the conclusion that the magnetic poles move from the point where the heat is applied. Subsequently, on repeating the experiment by which Barlow found that the magnetic virtue of iron disappeared at a white heat, he found that a full red heat was capable of effecting the same result. His paper, entitled "Some Peculiarities in the Magnetism of Ferruginous Bodies," published in the seventh volume of the Society's Memoirs, contains an able discussion of this interesting subject; results of a very striking character being obtained with bars magnetized either by electric currents or the inductive action of the earth. Mr. Sturgeon

found that on heating one part of a bar to a full red heat, the remainder acted just as if the heated portion had been removed altogether.

Mr. Sturgeon had shown, in his "Experimental Researches in Electro-Magnetism and Galvanism," published in 1830, that when two similar plates of iron are placed, one in each of two strong solutions of nitric acid of different degrees of strength, having a bladder partition between them, they form an active voltaic pair: a battery of ten such pairs enabled him to decompose water and to ignite metals. At the same time he showed the high rank held by iron as an electro-negative element, when associated with amalgamated zinc. In 1836 Daniell observed that iron is sometimes more efficient than platinum, in association with amalgamated zinc; and about the same time Roberts and Fyfe recommended the employment of iron in the construction of voltaic batteries. In 1839 Mr. Sturgeon constructed a battery, consisting of twelve iron gas tubes, furnished with strips of amalgamated zinc, which proved very efficient. Afterwards, in 1840, he fitted up ten cylindrical jars of cast iron, each eight inches high and three inches and a-half in diameter, with the same number of amalgamated zinc cylinders of about two inches diameter. Although the electro-motive force of an iron zinc pair is only about one-half that of a Daniell's cell, Mr. Sturgeon's cast iron battery may be advantageously employed in many cases, owing to its great simplicity and cheapness.

In an experimental investigation of the "Magnetic Characters of Simple Metals, Metallic Alloys, and Salts," published in the seventh volume of the Transactions of this Society, Mr. Sturgeon showed that several metallic alloys became endued with magnetic properties, although their constituents separately showed no such action. On the other hand, nickel and iron became almost entirely inert to magnetic action when combined with other metals. An alloy of iron

and zinc, in the proportion of 1 to 7, was found to be quite destitute of magnetic action.

In 1839 he published a memoir "On Marine Lightning Conductors," comprising an examination of the effects of lightning on shipping, with remarks on Mr. Harris's plan; and the description of a new system of conductors. Mr. (now Sir W. Snow) Harris, following Mr. Henley, placed a strip of copper into a groove let into each mast. An electrical discharge striking the top of the mast was thus to be conducted by the copper strip through the keel into the water. In the system recommended by Mr. Sturgeon, copper rods or metallic ropes are placed aft the shrouds of each mast. The upper extremities of these conductors are attached to the fore, main, and mizen tops, as distant from the masts as circumstances will allow. The lower ends are connected with the chains belonging to the aft shrouds of each mast, and continued by broad and stout straps of copper to the sheathing of the ship. The top and top-gallant masts are protected in a similar manner, their conductors being connected with those of the lower masts. If, therefore, lightning strike the top-gallant, it will descend in two streams on either side of the mast, and then over the sides into the sea. Lastly, in order to distribute the discharge as completely as possible, and thus still further to lessen its danger, he proposed to unite the conductors of the fore, main, and mizen, by means of copper rods or metallic ropes in the position of stays. Little attention seems to have been paid to the above system, which, nevertheless, secures many highly important advantages, of which the following may be enumerated. 1st. The conductors being for the most part entirely removed from any combustible material, and combined so as to divide amongst them any stroke of lightning, the danger of fire in consequence of lateral discharge is less to be apprehended. 2nd. The electric fluid is carried over the side of the vessel, which

obviates the great risk which might arise from lateral explosion near the combustible or explosive materials of a cargo, and particularly should any accident have occasioned any interruption of the complete continuity of a conductor passing through the hull. 3rd. The magnetizing effects on chronometers are diminished. And 4th. The labour and expense of the fitting a ship with conductors are considerably lessened. I have said that Mr. Sturgeon's system, however excellent, did not receive much attention from the existing authorities. In addition to this disappointment, he found himself involved in a dispute with Mr. Harris, who had been largely successful in introducing Mr. Henley's plan into the navy. The advancement of science is seldom facilitated by warm controversy, and in this instance it must be allowed that Mr. Sturgeon suffered himself to be betrayed into stronger language than was suitable to the occasion. But with respect to the scientific portion of the argument, I cannot but be of opinion that he had a decided advantage over his opponent. The chief subject of dispute was whether a vertical conductor communicating by its lower end with the earth will, when struck by lightning, produce strong electric disturbance to vicinal conducting bodies not in metallic connexion with the earth. Mr. Harris insists that the spark which is observed to pass between an insulated discharging rod and an insulated conductor very near it, is owing to an excess of electricity on one coating of the leyden jar, as compared with that on the other; so that complete neutralization not taking place, the discharging rod receives a charge which it is able to communicate to neighbouring bodies. This hypothesis is, however, entirely at variance with Dr. Priestley's investigation of the phenomenon, as well as the experiments of Weekes, and many others. But there can be no doubt that even admitting Mr. Harris's hypothesis, the lateral explosion must exist pre-eminently in a thunderstorm, the circumstances of which render it almost impossible to conceive that the total electricity of a cloud is just equal in amount to

the electricity induced by it on the earth's surface. But even were the lateral explosion disproved, it could not be denied that any electrical current must at its rise and fall tend to produce currents of induction, according to the laws discovered by Faraday and Henry. Such induced currents must, in the case of a lightning stroke, be excessive, and only estimable by direct experiments on conductors in the neighbourhood of one struck by lightning. It must also be remarked that any discharge will, according to the established laws of conduction of electric currents, distribute itself among all bodies in contact with the lightning conductor, in proportion to their conducting powers. The portion thus conveyed might indeed be numerically insignificant as compared with the main stream, but yet sufficient to create sparks, at disruptions of such weak conductors, capable of igniting combustible materials. For the above reasons, whatever good fortune may have hitherto attended the conductors at present used in the navy, I cannot but prefer Mr. Sturgeon's system, which removes the conductors as far as possible from contact with any portion of the ship or its cargo.

Atmospheric electricity was a subject to which Mr. Sturgeon devoted a great deal of attention, from the commencement of his scientific career. He was in the habit of raising a kite, the string of which, insulated at the lower end, had a fine wire laid in it. In all seasons and weathers, on high and low ground, in every hour of both day and night, did he pursue this interesting but somewhat hazardous* course of investigation. By the result of more than five hundred kite observations he confirmed the important fact, first discovered by Kinnersley and Beccaria, that the atmosphere in serene weather is uniformly positive with regard to the earth. He also proved that the higher we ascend the more positive does it become;

* See his "Caution to Experimenters with the Electrical Kite," which he published in consequence of having been nearly killed by a discharge from only one hundred yards of wired string, though no thunder was heard.

so that if the strata in which the kites are immersed are at altitudes corresponding to the series 1, 2, 3, 4, 5, their relative charges of positive electricity would be conveniently represented by those numbers. He also revived copper and silver from their solutions, and decomposed water by atmospheric electricity. I cannot forbear describing, in his own words, one of the many extraordinary electrical displays, of which Mr. Sturgeon was a witness. On June 14th, 1834, he writes: "The rain fell so heavily that it was with some difficulty I got the kite afloat; and when up, its greatest altitude did not exceed fifty yards. The silken cord also, which had been intended for the insulator, soon became so completely wet that it was no insulator at all. Notwithstanding all these impediments, I was much gratified with the display of the electric matter issuing from the end of the string to a wire, one end of which was laid on the ground and the other attached to the silk, at about four inches distance from the reel of the kite string. An uninterrupted play of the fluid was seen over the four inches of wet silken cord, not in sparks, but in a bundle of quivering purple ramifications, producing a noise similar to that produced by springing a watchman's rattle. The display was beautiful beyond description. The reel was occasionally enveloped in a blaze of purple arborized electrical fire, whose numberless branches ramified over the silken cord, and through the air to the blades of grass, which also became luminous on their points and edges, over a surface of some yards in circumference. We also saw a complete globe of fire pass over the silken cord between the wire and reel of the kite string. It was exceedingly brilliant, and about the size of a musket ball."

Having on another occasion elevated an electrical kite during a thunderstorm, he noticed that a shower of sparks was discharged from the string at the moment of each flash of lightning, a phenomenon which he accounted for by supposing that every flash of lightning disturbs all the electric

fluid around it, and thus produces an *electrical wave* which, in some instances, reaches to great distances.

Mr. Sturgeon noticed that thunderstorms are the most violent when they occur over wet ground or water, owing to the facility with which such a surface can be charged by the inductive influence of electrified clouds; and also that electrical storms generally travel in the direction of rivers or along narrow tracts of wet ground. In his description of the thunderstorm which occurred near Manchester on the 16th July, 1850, he made an observation which was probably more remarkable than any that had been previously made in atmospheric electricity. This consisted in the determination of the *time* of a lightning discharge by means of the vibrations of a pendulum; the *streams* of electric fluid being visible in some cases as long as a second and a-half. Mr. Clare and others, including myself, who witnessed the same phenomenon from different points of view, coincided in remarking that these streams of electric fluid took up a very sensible time, and that the motion of electricity along them was apparent. This extraordinary and magnificent spectacle seems to have been owing to the great elevation at which the lightning was playing, where the rarefaction of the air would probably cause it to assume some of the characteristics of the aurora borealis.

Mr. Sturgeon does not appear to have embraced any theory of the cause of thunderstorms. I may, however, remark, that after the discovery by Faraday that the enormous evolution of electricity in Armstrong's hydro-electrical apparatus is owing to the friction of particles of water and air, it is probable that the electricity of the thunder-cloud arises from the friction of the particles of water or ice of which it is composed, or which are falling from it, against the cold non-conducting air which exists at a high altitude.

The aurora borealis was a phenomenon in which Mr. Sturgeon took a great deal of interest. His observations of this

meteor extended over a period of more than twenty years. Its cause he attributes to a sudden change of temperature in the upper regions of the atmosphere, giving rise to a corresponding disturbance of the electric fluid. The attenuated air is, he conceives, illuminated by these extensive movements of electricity, which at the same time agitate the magnetic needle in conformity with the laws of electro-magnetic action. I think it must be allowed that a more intimate connexion subsists between the magnetism of the earth and the aurora than he seems disposed to admit, although few will, probably, embrace the very artificial hypothesis of Dalton. Mr. Sturgeon shows an excellent example of the spirit with which all mere hypothesis ought to be enunciated, in the concluding sentence of his "Observations on the Aurora Borealis," in which he says with much modesty, "It is possible, however, that the theoretical views which I have here advanced may be open to objections that I do not myself perceive, and may require the corrections of a more diligent observer, and a sounder reasoner on the facts observed."

The last contribution I shall notice is one on a subject of great scientific interest and practical importance, "the electro-culture of farm crops." Many philosophers of eminence had made the observation that plants grow more vigorously when they are electrified or galvanized; but the experiments of Dr. Forster, in 1845, appear to have been the earliest in which the atmosphere was employed as the electrifying agent. He suspended a wire in the air communicating metallically with a wire buried three inches deep and surrounding the plot experimented on. He found the yield of the ground, so electrified, to be considerably greater than that of the rest of the field. The experiments of Dr. Forster, variously modified, were repeated by Mr. Sturgeon with results sufficiently successful to encourage further investigation. I do not know whether any further trials have been made, but when we reflect upon the enormous quantity of electricity

almost constantly descending from the air through the leaves and roots of plants, it is impossible not to allow that great influence on vegetation is exercised by it, and it must be reasonable to infer that such influence may be increased or modified by collecting and distributing it by artificial means.

Having completed a rapid survey of Mr. Sturgeon's principal scientific researches and discoveries, it will be proper now to notice his career in the several capacities of editor, lecturer, and professor. Soon after leaving the army he was appointed Lecturer on Experimental Philosophy to the Hon. East India Company's Military Seminary at Addiscombe, and he continued to hold that position, with credit to himself, until, in the year 1838, he accepted the office of Superintendent of the Royal Victoria Gallery of Practical Science, an institution which was founded in this city by a few public spirited gentlemen, in the hope that by means of popular scientific discourses, illustrated by experiments with apparatus of a size and completeness unattainable by a private lecturer, interest would be excited and scientific education largely promoted. This expectation was, however, unhappily disappointed. The indifference to pursuits of an elevated character, which too frequently marks wealthy trading communities, destroyed this, as it has many other useful institutions. Undismayed by this failure, Mr. Sturgeon made strenuous efforts to establish another institution of a similar character, but which failed from the same cause which ruined its predecessor. After this he had no further connexion with any other educational establishment, and relied for support on the precarious emoluments arising from the courses of lectures he delivered in various parts of the country.

As a lecturer he was distinguished by his power of impressing the truths of science clearly and accurately on the minds of his auditory, and especially by the uniform success of his experimental illustrations. The following quotation, from one of his unpublished lectures, illustrating at once his

style of composition and his comprehensive view of the electrical agent, will be read with interest.—"Thus, ladies and gentlemen, I have, as far as this short course of lectures would admit, endeavoured to illustrate the principles of magnetism, and their connexion with electricity. I have shown you by a series of selected experiments, that there is not only a reciprocal action exercised by those mysterious powers upon each other; but, by *their* agency, some of the most wonderful and important phenomena of nature are produced.

"The electric fluid is so universally diffused throughout every part of nature's productions, that every particle of created matter, both animate and inanimate, which has hitherto been contemplated by the philosopher, is full of this surprizingly animated elemental fire.

"In regions far above the surface of the earth, where the air is much attenuated and so far thinned, near to the utmost verge of the atmosphere, as to become a conducting medium, the *electric element* plays its quivering streamers and sparkling corruscations in the beautiful aurora of the north. Sometimes this rare—this fascinating phenomenon is exhibited in a steady glowing arch of light; whilst at others, it expands its dancing network in transient display over the whole concave of the visible heavens.

"At altitudes less elevated than those which form the grand theatre for the display of the aurora borealis, the electric discharges become more compact, and shoot slanting downwards, on bright serene evenings, those beautiful gleaming orbs of meteoric light, which, from ancient custom, are still called falling stars.

"Still less elevated in the atmosphere the big black clouds swell with the *electrical element*, until bursting from its aerial walls it discharges itself into space, in all those grand, magnificent, and splendid forms of lightning, with their tremendous peals of thunder, so frequently displayed in most countries during the transient rage of a majestic summer's storm.

" Descending to the earth we trace its circumfluent streams polarizing this vast ball of matter, on which we are destined to live and perform all our actions, and insinuating its resistless influence in all the silent, mysterious, attractions of the *magnet.*

" Trace it to the laboratory of the chemist, and we find it the most active and vigorous agent in accomplishing all those astonishing changes which give new forms, and new qualities, to passive, obedient matter.

" Besides all these important operations of nature, accomplished by the agency of electricity, it is capable of restoring the dormant muscular and nervous powers of man, which have been prostrated by accident or disease; and of giving new life, and new vigor, to parts which have bid defiance to every other mode of medical treatment.

" In plants also, as well as in animals, it is said to facilitate their growth, and to give health, vigor, and beauty to their general appearance.

" Indeed, so *universally* does the electric fluid appear to be employed in *most*, if not *all*, the grand processes of nature, that there is not, perhaps, a plant that grows, nor a limb that moves, but is, in some measure, influenced by its powers.

" Nay, it is, perhaps, this astonishing, this most gigantic of physical agents, which is employed by the GREAT CREATOR to spin the earth and planets on their axes, to sweep them through the heavens in their regular periods of revolutions, and to keep in uniform motion all those massy orbs of matter which compose the countless systems of the universe.

" Brief and imperfect as is the outline which I have thus portrayed of *one individual* branch of science, perhaps we may venture to ask, who is there, then, who knows the advantages, the beauties, nay, the pleasures of scientific knowledge, who would think his time misspent, or his labours useless, in the accomplishment of so noble an acquisition?

" It is by the cultivation of the mind that one man be-

comes superior to, and has an absolute advantage over, another; and, by the study of science, the minutest process, and the most stupendous operation of nature, become alike delightful and familiar. The mind is thus led to explore the beautiful, the harmonious, the wondrous *works* of creation, and to admire and adore Creation's GOD."

In the year 1836 Mr. Sturgeon established a new scientific periodical, entitled the "Annals of Electricity, Magnetism, and Chemistry, and Guardian of Experimental Science," which he in the first instance published quarterly, but afterwards monthly. He conducted it with great ability, industry, and perseverance through ten octavo volumes. This work became the medium of the communication of much valuable information; and we are told that it gave rise to a similar publication, edited by Professor De la Rive, of Geneva. Subscribers to it were not sufficiently numerous to enable Mr. Sturgeon to continue it; but, nevertheless, after an interval of six months he made another attempt, which resulted in the appearance of the "Annals of Philosophical Discovery," which, however, he gave up after publishing six monthly numbers. Few, unhappily, care to read what it takes the slightest effort to understand; hence, with certain special exceptions, the sale of a publication may almost be said to be inversely proportional to the cultivation that may be expected from its perusal. Thus an inferior periodical literature is most generally read, while so little regard is paid to the phenomena of nature, or the theories of the philosopher, that a scientific magazine is nearly always a bad speculation, in a pecuniary point of view.

Mr. Sturgeon published several useful elementary works, of which the principal are:—"Lectures on Electricity, delivered in the Royal Victoria Gallery in 1841-42;" "A Course of Twelve Elementary Lectures on Galvanism;" and "A Familiar Explication of the Theory and Practice of Electro-gilding and Electro-silvering." He also prepared a transla-

tion of Jacobi's "Whole Galvanoplastic Art," and a new edition of Barlow's "Treatise on Magnetism." His last work, which was completed only a few weeks before his death, was a compilation, in one large quarto volume, of the whole of his published scientific papers, systematically arranged, preceded by an able historical sketch of electromagnetism, from its commencement until the year 1823.

That a man, whose whole life was spent in hard labour, both mental and bodily, and in the anxieties and deprivations incident to slender pecuniary resources, should have attained to the age of even 67 years, is somewhat remarkable, and shows, what other similar cases testify, how intimate a connexion subsists between the strength of the mind and the stamina of the constitution. Or, rather, does it not teach that the brain being kept under steady discipline, and in constant active employment, reacts on the body so as to produce a corresponding vigor in the functions by which life is sustained? Mr. Sturgeon continued, with little intermission, in a course of assiduous industry until ten days before his death, which took place at Prestwich, on Sunday, December 8th, 1851.

In considering the moral and intellectual qualities of this eminent man, it is needful to recollect that from his birth to 1820, an interval of 37 years elapsed, during which the circumstances of his position precluded almost entirely the cultivation of the higher faculties of the mind. Thus, to him, were wanting all those advantages which belong so eminently to early study; such as the stimulus of first ideas; freshness and pliability of imagination; the vigour and hopefulness of a mind unsoured with disappointment, and unclogged with the infirmities which begin to settle upon it when the meridian of life is scarcely attained. That Mr. Sturgeon succeeded at all with such a fundamental disadvantage, can only be attributed to the amazing elasticity and sanguineness of his temperament. This quality, so essential

to his position, and without which he would probably never have attained even mediocrity, must, nevertheless, be reckoned as the source of many of his embarrassments. On the one hand it made him look beyond and aim further than the mere acquisition of personal comfort; on the other hand it led him to embark in projects which entailed upon him trouble and loss. So true it is, that even the best qualities of the mind are to a certain extent, so to speak, double handed, and affect a man's happiness injuriously or beneficially according to the character of the individual, and the circumstances in which he is placed.

To see a man labouring hard for the good of society and the advancement of science without the possession of suitable means, is a spectacle which calls forth the liveliest sympathies of our nature. However noble the motives of such exertion, it is certain that a man is frequently placed in circumstances which render it a duty and virtue to deny himself the gratification of intellectual pursuits. If a family is dependent upon his labour for their daily bread,—if the claims of creditors are to be met,—then it may be his bounden duty to pursue the ordinary employment of society rather than his favourite researches, however important, if they are not accompanied by a steady and adequate remuneration. Frequently, however, it is difficult, or even impossible, for a man disappointed in his hopes of realizing an income by intellectual labour, to turn his attention successfully to ordinary business, and thus paralysed in all his efforts he becomes involved in crushing and hopeless penury. The sum which would be necessary to succour the needy man of science, and so to enable him to continue his researches, would appear trifling indeed if regard were had to the important objects to be realized. But he appeals not to his country as a pauper. He asks it to discharge the debt it owes for labours which have contributed to the common weal, a debt which cannot honourably be left unpaid.

In the case of Mr. Sturgeon, Government was induced, through the untiring exertions of my friend, E. W. Binney, F.R.S., &c. (to whom science owes so much for his kind assistance to its humble cultivators), to award a sum of £200., and afterwards a pension of £50., which, on Mr. Sturgeon's death, a year afterwards, was continued to his widow. These sums, along with the private efforts of his friends, alone saved him from being reduced to a state of destitution, which had it occurred would have reflected deep discredit upon the community.

Mr. Sturgeon was of a tall and well built frame of body; his forehead was high, and his features were strongly marked. His address was animated; and his conversation, as it generally is when the mind is stored with knowledge, pleasing and instructive. His style of writing was at once vigorous, lucid, and graceful. In friendship he was warm and steady; in domestic life affectionate and exemplary. He had a noble mind and a generous heart. In politics he was a conservative; in religion a member of the Church of England. He was a close and sagacious reasoner, and an unsparing exposer of error. He detested quackery and false pretension, sought diligently for truth, and loved it for its own sake. A diligent accumulator and observer of facts; eager in the pursuit of information, of whatever kind, and in communicating his stores to others; under more fortunate circumstances he would, probably, have left a name unsurpassed in the scientific history of his time; as it is, he will always be remembered as a distinguished cultivator of natural knowledge.

VI.—*On the Solubility of Sulphate of Baryta in Acid Solutions.*

By F. Crace Calvert, F.C.S., M.R.A. Turin, &c.

[*Read December 2nd*, 1856.]

There are few substances more frequently met with and which require to be determined with greater precaution than sulphur and its compounds, it is therefore of the highest importance to possess exact means of knowing their proportions.

Up to the present time it has been admitted that sulphate of baryta was so insoluble that it was sufficient to add a soluble salt of baryta to a solution containing a sulphate, with an excess of acid, either nitric or hydrochloric (so as to avoid the precipitation of other acids by the baryta), in order that the sulphuric acid existing in a liquor should be exactly determined. My researches have convinced me that sulphate of baryta *is* soluble in acids. I have succeeded, as will be seen further on, in dissolving two grains of sulphate of baryta in 1,000 grains of nitric acid of a specific gravity of 1.167; whilst it requires 140,000 grains of water to dissolve one grain of sulphate of baryta; and what is not less interesting is, that very weak nitric acid influences the solubility of sulphate of baryta; it is therefore essential not to acidify liquors with nitric acid.

This fact seemed to me so important for analytical chemistry, that I made a great number of researches in order to

know all the circumstances which influence the solubility of sulphate of baryta; and, although I have made several hundred experiments, I shall only give here the most striking, and those which tend to demonstrate the influence exercised by masses of matter, upon their chemical affinity. I hope that these last facts will offer the more interest, as we only possess few researches demonstrating, that Berthollet expressed a correct opinion, when he asserted that the quantity of matter present exercised an influence upon chemical affinity. However, since I have commenced these researches, in 1851, several works supporting these views have appeared, those of Messrs. Bunsen, Gladstone, Henry Deville, &c.

The first idea of these researches was suggested to me by an inquiry which I had undertaken to determine the quantity of sulphur in cast and malleable irons. As the quantity of sulphur to be determined only varied between the limits of 0.1 and 0.3, it was indispensable that I should take the greatest precautions; but, notwithstanding, I still found it impossible, in making two comparative analyses of the same iron, to obtain two sulphates of baryta having corresponding weights. Desiring to know the cause of error I made several experiments, and discovered, to my great surprise, that sulphate of baryta was freely soluble in acids, and then the error in my analyses was explained. Some quantitative analyses of water, which I had to make at the same time, led me to the same result; for having followed the ordinary process which consists in adding, in the case of a water which contains carbonates and sulphates, nitric acid to the residue left by the evaporation of a known quantity of water, I determined the quantity of sulphuric acid, and was again struck by the divergence of my results. If I had contented myself by taking the mean of the results obtained, I should have been obliged, in calculating the relation of the bases to the acids, to admit, as some chemists have done, that there were silicates

of magnesia and lime in the water, whilst by avoiding the solution of the sulphate of baryta, I arrived at the conclusion that the bases existed as sulphates and that the silica was free, or combined in small quantity with potash or soda.

Before giving the results of my experiments, which demonstrate the solubility of sulphate of baryta in acid solutions of different degrees of concentration, and the influence exercised by multiple volumes of nitric acid of specific gravity 1.167 on the same solubility, I shall give the method of operating which I followed.

Having placed in ten jars, of the same size, known quantities of perfectly pure sulphate of potash, I added to them a given bulk of nitric acid of sp. gr. 1.305, and a quantity of distilled water, such as when added to that which was employed to dissolve the nitrate of baryta, made a known total, which was in each successive jar a multiple of the quantity of water put in the preceding jar. When, instead of employing acids decreasing in strength, I wished to study the influence of increased volumes of the same acid, that used was of the sp. gr. 1.167 at 60°, or equal to 27.27 of anhydrous nitric acid and 72.73 of water per cent. This strength of acid was employed in preference to any other, because it was that which gave the *maximum* of solubility to the sulphate of baryta. I also took the precaution to use new jars, in order to avoid scratches, which influence the solubility of the sulphate of baryta; and equally avoided agitating the intimate mixture of the two salts, in order to be always, as far as possible, placed in the same circumstances, so that the results might be comparative.

I will give, first, several series of results which demonstrate the solubility of the sulphate of baryta; and afterwards will examine the facts which have special relation to chemical affinity.

SOLUBILITY OF SULPHATE OF BARYTA IN MULTIPLE VOLUMES OF NITRIC ACID.

The first series of experiments was made by placing in each jar a quantity of sulphate of potash, capable of producing 1.00 gr. of sulphate of baryta, and adding successively in each jar, multiple volumes of nitric acid having a sp. gr. of 1.167 at 60°, and on the sulphate being dissolved, pouring into it an equivalent quantity of nitrate of baryta, previously dissolved in a known volume of water.

TABLE No. 1.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167	Quantity of Sulphate of Potash.	Quantity of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a precipitate appeared.
1	40	466.8	0.735 gr.	1.121	0.999	Only in No. 1 did a cloud appear after 12 hours, and even after 24 hours the precipitate was very faint. No precipitate in the other nine jars.
2	80	933.6	.....	.....	.....	
3	120	1400.4	.....	.....	.....	
4	160	1867.2	.....	.....	.....	
5	200	2334.0	.....	.....	.....	
6	240	2800.8	.....	.....	.....	
7	280	3267.6	.....	.....	.....	
8	320	3734.4	.....	.....	.....	
9	360	4201.2	.....	.....	.....	
10	400	4668.0	.....	.....	.....	

On examining the above results, it will be observed that one grain of sulphate of baryta was almost entirely dissolved in 40 volumes of acid, or in 466.8 grs. of nitric acid, and entirely so in 933.6 grs. of the same acid, and that no precipitate was formed in the other eight jars, even after standing forty-eight hours. There was therefore more than 1 gr. of sulphate of baryta dissolved in 1000 grs. of acid. Desiring to obtain a precipitate in all the ten jars, I employed $4\frac{1}{2}$ times the above quantity of nitrate of baryta and sulphate of potash, and obtained the following results.

TABLE No. 2.

Order of Jars.	Number of Divisions of the Alkali-meter.	Corresponding Weight of Acid. Sp. gr. 1.167	Quantity of Sulphate of Potash.	Quantity of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a precipitate appeared.
1	40	466.8	3.34	5.00	4.46	instantly.
2	80	933.6	.....	.....	.....	20 minutes.
3	120	1400.4	.....	.....	.....	2 hours.
4	160	1867.2	.....	.....	.....	8½ hours.
5	200	2334.0	.....	.....	.....	24 hours.
6	240	2800.8	.....	.....	.....	no precipitate.
7	280	3267.6	.....	.....	.....	ditto
8	320	3734.4	.....	.....	.....	ditto
9	360	4201.2	. ...	.....	.....	ditto
10	400	4668.0	... ..	.....	.....	ditto

I was much surprised to find, that even after standing twenty-four hours, no precipitates were formed in jars Nos. 6, 7, 8, 9, and 10, although the quantity of salt employed was capable of giving rise to 4.46 of sulphate of baryta.

These results are also interesting in another point of view, viz., if we calculate the quantity of sulphate of baryta dissolved by 1000 grs. of acid in jar No. 6, the quantity found is 1.593, or in other terms, there is .592 more salt dissolved per 1000 grs. of acid, than in the jar No. 2 of No. 1 Table; this difference of solubility can only be owing to the influence exercised by a greater quantity of sulphate of potash and nitrate of baryta being employed, since everything else was equal. In pursuing the reading of this paper it will be seen that the influence exerted by quantity on mass is clearly confirmed. Having remarked that in the jars, Nos. 1, 2, 3, 4, and 5, of the above series, the precipitates diminished rapidly in quantity, I collected them, and washed them until the liquor gave no precipitate, either with sulphate of potash or nitrate of baryta; but these washings are very tedious, the nitrate of baryta or the sulphate in excess adhering to the sulphate of baryta with extraordinary tenacity; and this difficulty, as I will show further on, increases still more when the recom-

mendation given by some chemists is followed, viz., to add a great excess of nitrate of baryta to the liquor containing the sulphates.

TABLE No. 3.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167.	Quantity of Sulphate of Baryta Precipitated.	Quantity of Sulphate of Baryta Dissolved.	Quantity of Sulphate of Baryta dissolved in 1000 grains.
1	40	466.8	4.44	0.02	0.043
2	80	933.6	3.17	1.29	1.382
3	120	1400.4	2.02	2.34	1.670
4	160	1867.2	0.80	3 66	1.957

These figures show not only the rapid increase of solubility of sulphate of baryta in multiple volumes of nitric acid sp. gr. 1.167, but also that the formation of a precipitate does not prevent the great solubility of this salt.

Thus, in jar No. 2, there is 1.382 dissolved in 1000 grs.
„ No. 3, „ 1.670 „ „
„ No. 4, „ 1.957 „ „

Therefore in each successive jar there is 0.3 gr. more of sulphate of baryta dissolved for the same volume of acid.

In the hope of producing a precipitate in all the jars of the series, I employed a greater quantity of salts for the same proportions of acid as above, and the results are given in the following table.

TABLE No. 4.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167	Quantity of Sulphate of Potash.	Quantity of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a precipitate appeared.
1	40	466.8	5.12	8.00	7.13	instantly.
2	80	933.6	.....	.....	.....	2 minutes.
3	120	1400.4	.....	.....	.....	14 minutes.
4	160	1867.2	.....	.....	.....	1 hour.
5	200	2334.0	.....	.....	.....	1 hour 15 minutes.
6	240	2800.8	... ..	.....	.....	4 hours.
7	280	3267.6	.....	.....	.....	8 hours.
8	320	3734.4	.....	.....	.. ...	24 hours.
9	360	4201.2	.. ...	.....	.....	none.
10	400	4668.0	.....	.....	.....	none.

Although the quantity of salt employed in this case was capable of producing 7.13 grs. of sulphate of baryta, still, after twenty-four hours there was no precipitate produced in jars No. 9 and 10, and in order to obtain a precipitate in all the jars composing a series, I was obliged to employ quantities of salts of baryta and potash, capable of producing 10.0 grs. of sulphate of baryta.

In order to confirm the results given in Table No. 3, the precipitates formed in the above series were collected, and their weight determined.

TABLE No. 5.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167.	Quantity of Sulphate of Baryta Precipitated instead of 7.13.	Quantity of Sulphate of Baryta Dissolved.	Quantity of Sulphate of Baryta dissolved in 1000 grains.
1	40	466.8	6.86	0.27	0.591
2	80	933.6	5.63	1.50	1.615
3	120	1400.4	4.66	2.47	1.767
4	160	1867.2	3.22	3.91	2.099
5	200	2334.0	2.33	4.80	2.059
6	240	2800.8	1.10	6.03	2.155
7	280	3267.6	0.14	6.99	2 141

These results prove that 1000 grs. of nitric acid sp. gr. 1.167, are able to dissolve about 2 grs. of sulphate of baryta.

ON THE INFLUENCE EXERCISED BY AN EXCESS OF PRECIPITANT.

As it is generally admitted that an excess of precipitant increases the chances of obtaining the total precipitation of the sulphate in solution, I thought it useful to make a series of experiments to ascertain if these views were correct, and it will be seen, by comparing the results given below with those of Table No. 2, in which equivalent quantities were used, that such is not the case, since the results in the two tables are identical.

TABLE No. 6.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167	Quantity of Sulphate of Potash.	Quantity of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a precipitate appeared.
1	40	466.8	3.34	10.00	4.46	instantly.
2	80	933.6	.....	.....	.....	5 minutes.
3	120	1400.4	.....	.....	.....	37 minutes.
4	160	1867.2	.....	.....	.....	2 hours 30 minutes.
5	200	2334.0	.....	.....	.....	5 hours.
6	240	2800.8	.....	.....	.....	24 hrs. distinct cloud
7	280	3267.6	.....	.....	.....	no precipitate.
8	320	3734.4	.....	.....	.....	ditto
9	360	4201.2	.....	.....	.....	ditto
10	400	4668.0	.....	.....	.....	ditto

But this method of operating, namely, employing an excess of precipitating agent, offers, as I have already said, great inconveniences in consequence of an excess of precipitant adhering to the sulphate of baryta, which necessitates numberless washings. To avoid prolonging this paper, I shall state that the same difficulties present themselves when two equivalents of sulphate of potash are employed for one equivalent of nitrate of barytes.

INFLUENCE OF BOILING, UPON THE FORMATION OF SULPHATE OF BARYTA.

TABLE No. 7.

Order of Jars.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167	Quantity of Sulphate of Potash.	Quantity of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a precipitate appeared.
1	40	466.8	3.34	5.00	4.46	instantly.
2	80	933.6	.....	.....	.....	3 minutes.
3	120	1400.4	.....	.....	.....	8 hours.
4	160	1867.2	.....	.....	.....	24 hours.
5	200	2334.0	.....	.....	.....	no precipitate.
6	240	2800.8	.....	.....	.....	ditto
7	280	3267.6	.....	.....	.....	ditto
8	320	3734.4	.....	.....	.....	ditto
9	360	4201.2	.....	.....	.....	ditto
10	400	4668.0	.....	.....	.....	ditto

On comparing the results contained in this table with those in Table No. 2, it is observed that the formation of sulphate of baryta is not facilitated by boiling. This fact was often confirmed during the course of my experiments, by taking the clear solutions which remained when the precipitate of sulphate of baryta had subsided and bringing them to ebullition, without in any case obtaining a precipitate.

EMPLOYMENT OF SULPHURIC ACID INSTEAD OF SULPHATE OF POTASH.

I thought it right to make the following series of experiments, in order to ascertain that the non-formation of sulphate of baryta, in a liquor rendered acid by nitric acid, was not owing to a combination being formed between the sulphate of potash and the nitric acid; to attain this object, I poured into each multiple volume of nitric acid a quantity of sulphuric acid, equivalent to that contained in 3.34 grs. of sulphate of potash, and the results obtained were identical with those observed in Table No. 2; consequently no combination was formed between the nitric acid and the sulphate of potash.

TABLE No. 8.

No. of Jar.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid. Sp. gr. 1.167	Sulphuric Acid, equal to 1.533, capable of producing 4.46 Ba O S O_3	Weight of Nitrate of Baryta.	Time when a precipitate appeared.	Weight of Nitrate of Baryta.	Time when a precipitate appeared.
1	40	466.8	1.533	5.00	instantly.	10.00	instantly.
2	80	933.6	.....	.....	13 minutes.	.....	6 minutes.
3	120	1400.4	.....	.....	2 hrs. 30 min.	.....	30 minutes.
4	160	1867.2	.....	.....	7 hours.	.....	1 h. 15 min.
5	200	2334.0	.. ...	.....	24 hours.	.....	5 h. 30 min.
6	240	2800.8	.....	.....	no precipitate	.....	7 h. 30 min.
7	280	3267.6	.....	.....	ditto	.....	24 hours.
8	320	3734 4	.....	.....	ditto	.....	no precipitate.
9	360	4201.2	.....	.....	ditto	.....	ditto
10	400	4668.0	.... .	.....	ditto	.....	ditto

I also made several series of experiments, dissolving first the nitrate of baryta in the nitric acid, and then pouring into it the sulphate of potash; but this mode of operating did not

produce any alteration in the results obtained. During this series of experiments, I determined the solubility of nitrate of baryta in nitric acid sp. gr. 1.167 at a temperature of 60°.

1	grain of	nitrate of	baryta	requires 250.2
2.5	,,	,,	,,	446.8
5.0	,,	,,	,,	933.8
6.5	,,	,,	,,	1334
8.0	,,	,,	,,	2800
10.0	,,	,,	,,	3267

ON THE INFLUENCE EXERCISED BY DIFFERENT DEGREES OF CONCENTRATION OF NITRIC ACID ON THE FORMATION OF SULPHATE OF BARYTA.

In the following series of experiments I operated in an entirely different manner; the same quantity of nitric acid, sp. gr. 1.305, was put into each jar, and to each was added multiple volumes of water; therefore, each solution decreased in density; and after having dissolved the quantity of sulphate of potash which I intended to employ, I poured in the solution of nitrate of baryta.

On comparing the experiments contained in the following table, it will be seen that I have obtained results very different from the preceding, for instead of 4.46 of sulphate of baryta remaining in solution in the last five jars, as was the case when I employed the same quantities of salt in multiple volumes of the same acid, precipitates were found in all the jars, and that in the space of three minutes; therefore, multiple volumes of acid, decreasing in strength, do not exert the same influence as the increase of volume of the same acid. This table also presents a fact important for chemical analysis, viz., that the solubility of sulphate of baryta is affected even by the weakest acid, since 2200 grs. of nitric acid, sp. gr. 1.032, are capable of dissolving 0.08 of sulphate of baryta; this solubility, though slight, is still five times greater than it would be in distilled water.

TABLE No. 9.

Order of Jars.	Number of Divisions of the Alkali-meter of Nitric Acid Sp. gr. 1.305.	Number of Divisions of the Alkali-meter of Water added to the Acid.	Sp. gr. of the Acid.	Sulph. of Potash dis-solved in the Acid.	Nitrate of Baryta.	Time when a precipitate appeared.	Quantity of Sulphate of Baryta precipi-tated in-stead of 4.46.	Quantity of Sulphate of Baryta dissolved.
1	20	20	1.167	3.34	5.00	3 minutes	4.28	Average quantity dissolved equal to 0.10.
2	20	40	1.120	.....	.....	.....	4.34	
3	20	60	1.085	.....	.....	.....		
4	20	80	1.067	.....	.....	.....		
5	20	100	1.057	.....	.....	.....	4.35	
6	20	120	1.050	.....	.....	.....	4.35	
7	20	140	1.044	.....	.....	.....	4.36	
8	20	160	1.039	.....	.....	.....		
9	20	180	1.035	.....	.....	.....		
10	20	200	1.032	.....	.....	.....	4.38	

The series of experiments which follows, was made with the view of knowing what would be the influence of a less quantity of nitrate of baryta for the same quantity of sulphate of potash, and it will be seen, in perusing the table, that instead of obtaining a precipitate in all the jars in three minutes, the time required was from 2 hours 30 minutes to 24 hours, although, with the exception of the quantity of nitrate of baryta, everything was equal.

TABLE No. 10.

Order of Jars.	Number of Divisions of the Alkali-meter of Nitric Acid Sp. gr. 1.305.	Number of Divisions of the Alkali-meter of Water added to the Acid.	Sp. gr. of the Acid.	Sulphate of Potash dissolved in the Acid.	Nitrate of Baryta poured in.	Time required for a Precipitate to appear.
1	20	20	1.167	3.34	0.25	2 hours 30 minutes.
2	20	40	1.120	.....	.....	2 hours 45 minutes.
3	20	60	1.085	.....	.....	2 hours 45 minutes.
4	20	80	1.067	.....	.....	6 hours.
5	20	100	1.057	.....	.....	6 hours.
6	20	120	1.050	.....	.....	24 hours.
7	20	140	1.044	.....	.....	24 hours.
8	20	160	1.039	.....	.....	24 hours.
9	20	180	1.035	.....	.....	24 hours.
10	20	200	1 032	.....	.....	24 hours.

I thought that it would be interesting to know what would be the *minimum* quantity of nitrate of baryta necessary, in

order that no precipitate should be formed in any of the jars of the series, when 3.34 of sulphate of potash was in solution, and the following table gives the results obtained.

TABLE No. 11.

Order of Jars.	Number of Divisions of the Alkalimeter of Nitric Acid Sp. gr. 1.305.	Number of Divisions of the Alkalimeter of Water added to the Acid.	Sp. gr. of the Acid.	Sulphate of Potash dissolved in the Acid.	Nitrate of Baryta poured in.	Time required for a Precipitate to appear.
1	20	20	1.167	3.34	0.062	No precipitate after 24 hours in any of the jars.
2	20	40	1.120	.....	.....	
3	20	60	1.085	.....	.....	
4	20	80	1.067	.....	.....	
5	20	100	1.057	.....	.....	
6	20	120	1 050	.....	... ..	
7	20	140	1.044	.....	.....	
8	20	160	1.039	.....	.....	
9	20	180	1.035	.....	.....	
10	20	200	1.032	.....	.....	

HAS THE FORMATION OF A PRECIPITATE AN INFLUENCE ON THE SOLUBILITY OF SULPHATE OF BARYTA.

It is generally believed that the formation of a precipitate tends to increase its quantity, but if this opinion be correct with regard to crystalline precipitates, such as those of bitartrate of potash, carbazotate of potash, &c., it is *not* so with sulphate of baryta; for it will be seen, in the following table, that the quantity of sulphate of baryta which remains dissolved in 1000 grs. of nitric acid, sp. gr. 1.167, at 60° Fah., is the same, whether there is or is not a precipitate formed in the liquors.

Order of Table.	No. of Jar.	Quantity of Acid Sp. gr. 1.167 employed.	Weight of Sulphate of Baryta dissolved.	Quantity of Acid.	Weight of Sulphate of Baryta dissolved per 1000gs.	Remarks.
2	5	2334 0	4.46	1000	1.957	With no precipitate.
3	4	1867.2	3.66	...	1.911	With a precipitate.
4	8	3734.0	7.136	...	1.919	With no precipitate.
5	5	2334.0	4.806	...	2.059	With a precipitate.
Results with 15 grs. $BaOSO_3$	9	4201.2	9.130	...	2.066	ditto
	10	4668.0	10 470	...	2.149	ditto

ON THE INFLUENCE OF MASS ON CHEMICAL AFFINITY.

When the results contained in the preceding tables are compared, there is observed a certain number of facts which demonstrate the influence of masses of matter "put in presence;" and in order to corroborate this assertion, I add here a certain number of results, extracted from the preceding tables.

1. If we compare the results given by the two first jars in Tables Nos. 1, 2, and 4, it will be seen that, although the same quantity of acid was employed, the time necessary for the formation of a precipitate varied considerably.

Order of Table.	Quantity of Acid employed.	Weight of Sulphate of Potash.	Weight of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Time when a Precipitate appeared.
1	466.8	0.753	1.121	1.00	12 hours.
	933.6	0.753	1.121	1.00	none.
2	466.8	3.34	5.00	4.46	instantly.
	933.6	3.34	5.00	4.46	2 hours.
4	466.8	5.12	8.00	7.13	instantly.
	933.6	5.12	8.00	7.13	2 minutes.

The differences observed above can only be owing to the fact that, for the same quantity of fluid, increasing proportions of nitrate of baryta and sulphate of potash were employed; for it cannot be explained by admitting that it is owing to there not being a sufficient quantity of nitric acid to hold a greater quantity of sulphate of barytes in solution; for if we calculate how much sulphate of baryta remains dissolved in 1000 grs. of acid, it will be seen that the quantities are the same in each of the three tables.

Order of Table.	Order of Jars.	Quantities of Acid employed.	Quantities of Fluid represented by.	Weight of Sulphate of Baryta dissolved.
1	1	466.8	1000	2.142
2	4	1867.2	...	2.389
	5	2334.0	...	1.911
4	7	3267.6	...	2.182
	8	3734.4	...	1.909

Neither can it be admitted that the difference observed is owing to the formation of a precipitate, for I have shown above that the presence of a precipitate has not any influence on the degree of solubility or non-formation of sulphate of baryta.

2. The increased solubility of sulphate of baryta, arising from the presence of quantities of matter, can only be explained by admitting that this solubility is influenced by the increased quantities of salt employed, since the volume of acid is the same in every case, and all other circumstances are equal.

Order of Table.	Order of Jar.	Quantity of Acid employed.	Quantity of Sulphate of Baryta dissolved.	Quantity of Sulphate of Baryta dissolved per 1000grs.	Increased ratio of solubility per 1000grs. of Acid.
1	2	933.6	1.00	1.072	
2	6	2800.8	4.46	1.522	.450
4	9	4201.2	7.13	1.912	.390

I will again introduce the figures given above, as they show in a striking manner the rapid increase of the solubility of sulphate of baryta, for 1000 grs. of acid, in three successive jars of the same series.

Order of Table.	Order of Jar.	Number of Divisions of the Alkalimeter.	Corresponding Weight of Acid Sp. gr. 1.167.	Weight of Sulphate of Baryta precipitated.	Weight of Sulphate of Baryta dissolved.	Weight of Sulphate of Baryta dissolved per 1000grs.
1	1	40	466 8	4.44	0.02	0.043
	2	80	933.6	3.17	1.29	1.382
	3	120	1400.4	2.02	2.34	1.670
	4	160	1867.2	0.80	3.66	1.957

Therefore it appears to me that we must admit that the difference observed is due to the quantities of matter "put in presence."

I would also, in conclusion, call attention to the enormous differences between the effects of multiple volumes of an acid, compared with volumes of the same acid decreasing in density.

ON THE SOLUBILITY OF SULPHATE OF BARYTA IN HYDROCHLORIC ACID.

I thought it advisable to repeat some of the above series, substituting hydrochloric acid for nitric acid, and it will be seen that although sulphate of baryta is less soluble in this acid than in nitric acid, still it is sufficiently so, to cause chemists to avoid its use in excess in delicate analyses.

The following table shows the results obtained by employing multiple volumes of hydrochloric acid, of sp. gr. 1.0775, with quantities of nitrate of baryta and sulphate of potash, capable of producing 1 gr. of sulphate of baryta.

TABLE No. 12.

Order of Jar.	Divisions of the Alkalimeter of Acid Sp.gr.1.0775	Weight of Sulphate of Potash.	Weight of Nitrate of Baryta.	Weight of Sulphte. of Baryta.	Weight of Sulphate of Baryta obtained instead of 1.00	Weight of Sulphate of Baryta dissolved.	Time when a Precipitate appeared.
1	40	0.735	1.121	1.00	.96	.04	1¾ minute.
2	80	.....	.....	.....	.85	.15	9 minutes.
3	120	.....	.....	.....	.83	.17	50 minutes.
4	160	.....	.....	.....	.66	.34	3¾ hours.
5	200	.....	.....	.....	.48	.52	10 hours.
6	240	.....	.....	.....	.22	.78	24 hours.
7	280	.....	.....	.....	no precip.	1.00	no precipitate.
8	320	.....	.....	.....	.....	.....	.....
9	360	.....	.....	.....	.....	.....	.....
10	400	.....	.....	.....	.....	.....	.....

On comparing the results contained in this table with those of No. 1 Table of the nitric acid series, it will be seen that instead of the non-formation of a precipitate in jar No. 2, one was produced in the first six jars; sulphate of baryta, therefore, is less soluble in hydrochloric acid than in nitric acid, and still if we calculate, taking for term of comparison the results obtained in jar No. 7 of hydrochloric acid, it will be found that its solubility is equal to one part of sulphate of baryta in 2800 parts of hydrochloric acid; and consequently the solubility of sulphate of baryta in hydrochloric acid, sp. gr. 1.0775, is fifty times greater than in distilled water.

I have also made a series, employing the same quantities of salt of potash and of baryta, as in series No. 2 of nitric acid.

TABLE No. 13.

Number of Jar.	Divisions of the Alkalimeter of Acid Sp.gr.1.0775	Weight of Sulphate of Potash.	Weight of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Weight of Sulphate of Baryta obtained instead of 4.46.	Weight of Sulphate of Baryta dissolved.	Time when a Precipitate appeared.
1	40	3.34	5.00	4.46	4.35	.11	instantly.
2	80	.....	.....	.....	4.34	.12	instantly.
3	120	.....	.....	.....	4.24	.22	20 seconds.
4	160	.....	.....	.....	4.20	.26	1¼ minute.
5	200	.....	.....	.....	4.14	.32	2 minutes.
6	240	.....	.....	.....	4.14	.32	3½ minutes.
7	280	.....	.....	.....	4.17	.29	6 minutes.
8	320	.....	.....	.....	3.94	.52	9 minutes.
9	360	.....	.....	.....	3.98	.48	13 minutes.
10	400	.....	.....	.....	3.96	.50	18 minutes.

I have also made a series of experiments, employing no longer multiple volumes of the same acid of a constant strength, but multiple volumes of acid decreasing in strength, and it will be observed that the results in this last table are comparable with those of Table No. 7 of the nitric acid series.

TABLE No. 14.

No. of Jar.	Divisions of the Alkalimeter of Acid Sp. gr. 1.1425	Divisions of Water added.	Weight of Sulphate of Potash.	Weight of Nitrate of Baryta.	Weight of Sulphate of Baryta.	Weight of Sulphate of Baryta obtained instead of 4.46.	Weight of Sulphate of Baryta dissolved.	Time when a Precipitate appeared.
1	20	20	3.34	5.00	4.46	4.31	Average	instantly.
2	20	40	...	...	...		quantity dis-	instantly.
3	20	60	...	...	...		solved equal	instantly.
4	20	80	...	...	...	4.31	to 0.15.	15 seconds.
5	20	100	...	...	...			ditto
6	20	120	...	...	..	4.32		ditto
7	20	140	...	...	...			20 seconds.
8	20	160	. .	...	...			ditto
9	20	180	...	...	...			ditto
10	20	200	...	..	...	4.35		ditto

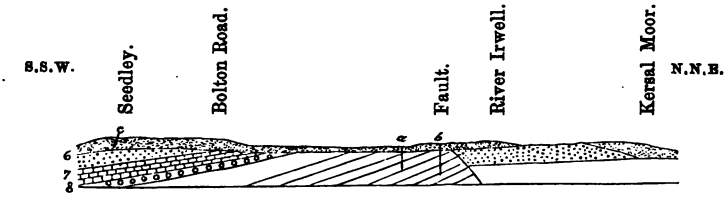
VII.—*Additional Observations on the Permian Beds of the North-west of England.*

By E. W. Binney, V.P.; F.R.S., F.G.S.

[*Read 24th February*, 1857.]

In a former communication made to this society on the permian beds of the north-west of England, and printed in vol. XII. (new series) of its Memoirs, I have alluded to the fragmentary condition in which our knowledge on this subject was. I then published what information I had obtained as an outline, trusting that other parties better qualified for the task would fill up the vast gaps that I had passed over. Since that time I have collected some further information on the subject at Seedley and Astley, near Manchester; Irby Hall, near Kirby-in-Lonsdale, and Howrigg, Shawk and Westward, near Wigton, Cumberland. This I now hasten to lay before the society, in the hope that it may probably induce other labourers to work on the permian deposits of this and the neighbouring districts.

SEEDLEY SECTION.



Middle and Upper Coal Field.

a and *b*. Mr. Fitzgerald's old and new coal pits.
c. Seedley bore hole.
6. Trias.
7. Red marls and limestones.
8. Conglomerate.

At page 231, in the paper before alluded to, under the head of "Pendleton," there was given a section of the strata lying between Oatbank, on the Eccles New Road, and Kersal Moor, both well known places in the immediate vicinity of Manchester, and lying to the north and west of the city. In that section, the upper new red sandstone, the lowest member of the trias, was laid down; but the permian deposits, although supposed to lie under the drift between Oatbank and the Bolton New Road, north-west of Pendleton, were not put in, no direct evidence of their occurrence in that part having been then obtained.

Mr. Appleby, of the Seedley Printing Company, has lately made a bore hole at their works in Seedley, for the purpose of increasing the supply of water there. In the spring of 1856 he called upon me for the purpose of ascertaining the character of the deposits lying under the upper new red sandstone, in which rock he had already several bore holes. I informed him that it was pretty certain that the upper permian beds, namely, the red marls with thin beds of limestone, would be about 130 feet in thickness; but the inferior portion, namely, the conglomerate and lower new red sandstone, were rocks of so variable a nature that it was impossible to say how thick they might be—whether 6 feet or 600 feet. Mr. Appleby has since

favoured me with a copy of the bore, and samples of the strata gone through. The hole was 15 inches in diameter, and was made by Messers. Mather and Platt, of Salford, with their new apparatus for boring. On the whole work the workmen, I am informed, averaged from eight to nine feet a day, and during their passage through the upper new red sandstone, they generally went three feet per hour;—certainly a very extraordinary speed for such a bore. The following is a list of the beds gone through:—

	Ft.	In.		
Till	61	0	Drift.	
Soft red sandstone with a few small rounded quartz pebbles in it	139	0	Trias.	
Very tenacious red clay	8	0	Red marls and thin beds of limestone	Permian.
Hard red raddle, very close in texture	0	6		
Red clay and red gritty sandstone	1	6		
Red clay, red gritty sandstone, and whitish gray rock, the latter soft	6	0		
Red clay and beds of stone	16	0		
Ditto	28	0		
Red clay	4	0		
Hard white rock	2	0		
Red clay with thin beds of stone	4	0		
Ditto	59	6		
White rock	0	6	Conglomerate.	
Red sandstone with beds of raddle	11	6		
Bluish-white stone, rather soft	0	6		
Clay with shale containing coal plants	30	0	Carboniferous	
	372	0		

Now, in the above section the upper permian beds, namely, the red clays (marls) with thin beds of limestone, are 128 feet in thickness—just about what was expected; but the lower beds, which, when last seen at Collyhurst, two miles and a-half to the south-east, were 350 feet in thickness, and at Patricroft, on the west, within one mile and a-half of Seedley, were 21 feet, only proved to be 12 feet 6 inches thick. These beds bear no resemblance to the soft crumbling sandstone at Heaton Mersey, Beet Bank Bridge, and Collyhurst, but are

like the conglomerates of Cheetham weirhole and Patricroft; and I am, therefore, inclined to class them as such. They are, I believe, as stated in my former paper, at page 266, often unconformable to the underlying lower new red sandstone upon which they rest.

The clay, with beds of shale, 30 feet in thickness, was good coal measures, as the lighter coloured beds were full of the rootlets of *Stigmaria ficoides*.

The occurrence of coal measures at this place is of considerable importance, as they were met with at a depth of only 115 yards from the surface, and if a good seam of coal could be found the field is of tolerable extent, and, from its position, would certainly command a first-rate market. The strata which I examined afforded no evidence of what part of the coal-field they belonged to; but, from the position of the Pendleton seams on the north-east, and the Patricroft ones on the west, they probably belong to the upper coal-field. The most likely seam to be found is the Openshaw coal, formerly worked near the Water Works Reservoir, in Beswick, near Manchester, and occupying a geological position near to the Slack Lane coal, formerly worked by Messrs. Lancaster at Monton.

Astley Section.

At pages 235 and 268 of my former paper, I gave particulars of a bore hole made by G. P. Kenworthy, Esq., in a field called the Horse Pasture, in Astley. In the upper permian beds there, fifty-five beds of limestone had been met with in a distance of 230 feet 6 inches. Many of these contained fossils of the genera *Schizodus*, *Bakevellia*, and *Tragos*. By the kindness of my friend, H. Mere Ormerod, Esq., I am enabled to add the following additional particulars, which carry the section through the lower permian beds into the coal measures.

	Ft.	In.	
Brown rock with water	10	0½	
Ditto	6	8½	
Ditto	5	4½	
Ditto burr	1	5¼	
Ditto soft	0	10½	
Ditto hard	10	8	
Whitish rock	1	0	
Brown-red rock	4	5	
Hard burr	1	1½	
White sandstone	4	11	
Irony burr	0	6	
Brown-red rock	2	7	
Red metal	0	5½	
Brown-red rock	34	6¼	
Hard burr	2	2	
Soft bed	0	1	
Hard burr	1	0	
Brown-red rock	0	7	
White or gray rock	2	1	
Brown and red rock burr	1	2½	
Ditto	3	0	
Ditto	7	10½	
Bright red rock	11	6½	
Burr	0	10½	
Bright red rock	3	0	
Ditto very hard	4	4½	
Red ironstone burr	1	6	
Bright red rock	11	7	
Red burr	0	6	
Red rock or linsey	6	0	
Red rock with clay	2	8	
Red burr	2	4	
Red rock	5	2	
Red raddle	0	9	
Red rock	0	11	
Blue metal	3	0	
Black shale	1	4	
Red metal	7	0	
Black shale	0	10	
Linsey	0	7	
Blue metal	3	1½	
White rock	0	7	
Black shale with ironstone bands	3	7	
Rocky warrant	4	4	
Red and blue metal	4	4	
Black shale	0	10	

Lower Permian.

	Ft.	In.	
Blue metal	9	5½	Carboniferous.
White rock	0	5	
Blue metal	1	1½	
Strong white rock	0	9	
Blue metal	1	0	
White rock	0	5	
Blue metal	1	3	
White rock	3	0½	
Dark blue metal	5	8	
Strong white rock	1	8	
Blue metal	1	1	
White rock	0	4	
Blue metal	6	2	
Whitish blue metal	7	6½	
Black bass	0	2½	
Smut of coal	0	1½	
Warrant	3	11	
White rock	7	2½	
Linsey	6	1	
White rock	7	5	
Blue metal	4	0	
Black shale	0	3½	
White rocky warrant	5	2	
Hard white burry rock	0	6	
Light gray metal	0	8	
Light blue metal	10	5	
Black shale	0	3	
Light gray metal	4	0	
Gray linsey	1	9	
Light blue metal	4	4	
Gray linsey	3	11	
Strong white rock	0	11	
Gray linsey	0	10	
White rock	2	5	
Gray metal or linsey	0	3	
White rock	2	10	
Gray burr, very hard	2	1	
White rock	1	1½	
Burr	0	11½	
Parting of blue metal	0	3	
White rock	0	8½	
	522	8	

This section gives a thickness of 150 feet $2\frac{3}{4}$ inches for the lower permian beds.* The coal measures appear to belong to the upper field, and although 153 feet 7 inches were penetrated, no seam of coal was met with.

By the further kindness of Mr. H. Mere Ormerod I have been furnished with a copy of the strata met with by Messrs. Sam Jackson and Co., in sinking their new pit down to the Four Feet seam of coal at Bedford Lodge. This working lies a little to the south of the places where the permian beds described by Mr. G. Wareing Ormerod, M.A., F.G.S.,† were met with, and not a great distance on the rise from Mr. Kenworthy's bore hole, previously alluded to in this paper. The dip of the strata is slightly east of south, at an angle of 9°; and as this is one of the best sections of the permian beds ever met with in Lancashire, I shall give it at length:—

	Yds.	Ft.	In.	
Soil	0	0	10	Drift.
Yellow clay and marl	1	0	2	
Dry lum and gravel	0	2	8	
Fine sand, very wet	0	1	0	
Lum and gravel, very wet	1	0	10	
Gravel, wet	0	1	4	
Sand, wet	0	1	0	
Fine gravel, wet	0	2	0	
Soft red rock	1	2	6	Trias.
Soft red rock band and gray rock	2	0	4	
Soft red rock with gray bands	3	0	6	
Yellow rock	0	0	9	
Soft red metal	0	1	6	
Red metal, rather stronger	2	1	7	
Fine light blue metal	0	0	1	
White gritty rock like bone or a bed of magnesia	0	0	1	
Soft red metal	6	2	0	
Soft white rock	0	0	8	
Red metal	0	1	4	

* This is about the thickness of the rock at Edge Green. See page 243 of the author's former paper.

† Quarterly Journal of the Geological Society of London, Vol. VII., page 268.

	Yds.	Ft.	In.
Soft red metal	0	2	6
Soft gray rock	0	0	8
Red metal	0	1	10
Gray rock	0	0	10
Red metal	2	2	6
Soft blue metal	0	0	2
Hard bastard limestone	0	0	3
Soft red metal	1	1	8
Red metal, rather stronger	0	2	4
Red stone bind or floor	1	0	6
Red stone bind, softer	1	2	2
Light blue metal	0	0	1
Soft red metal	1	0	7
Light blue metal	0	0	1
Red metal flooring	0	2	2
Red metal	0	1	0½
Light blue metal	0	0	2
Red metal	0	1	3½
Stony blue rock	0	0	5
Red metal	2	1	4
Blue metal	0	0	2
Red metal	0	0	6
Blue ditto	0	0	2
Red ditto	0	0	2
Blue ditto	0	0	2
Red ditto	0	0	4
Top band of limestone	0	0	5
Red metal	0	0	4
Blue metal	0	0	1
Red ditto with streaks of blue	0	1	4
Blue ditto with streaks of red	0	0	5
Red ditto	0	0	4
Blue ditto	0	0	2
Mainband limestone	0	0	11½
Red metal	0	0	2¼
Limestone	0	0	7
Blue metal	0	0	1
Red ditto	0	0	1½
Blue ditto	0	0	1½
Red ditto	0	0	2
Limestone	0	0	1½
Red metal	0	0	1½
Limestone	0	0	2
Blue metal	0	0	1
Red ditto	0	0	1
Blue ditto	0	0	0½

	Yds.	Ft.	In.	
Red metal	0	0	4¼	Upper Permian. Red and variegated marls and limestones.
Blue ditto	0	0	1	
Red ditto	0	0	1	
Limestone	0	0	4	
Red metal	0	0	0½	
Limestone	0	0	1¼	
Red metal	0	0	2½	
Limestone	0	0	3½	
Red metal	0	0	0½	
Limestone	0	0	1	
Red metal	0	0	1	
Limestone	0	0	5	
Red metal	0	0	2½	
Limestone	0	0	4	
Blue metal	0	0	3	
Red ditto	0	0	4	
Limestone	0	0	3	
Red metal	0	0	0½	
Limestone	0	0	1½	
Blue metal	0	0	1⅛	
Red ditto	0	0	2½	
Limestone	0	0	1⅛	
Red metal	0	0	4½	
Limestone	0	0	4	
Red metal	0	0	2	
Limestone	0	0	1	
Red metal	0	0	4½	
Limestone	0	0	1	
Red metal	0	0	1	
Limestone	0	0	2	
Red metal	0	0	3	
Limestone	0	0	1	
Red metal	0	0	4½	
Bottom limestone band	0	0	3	
Blue metal	0	0	1	
Red metal with blue streaks	2	0	0	
Red metal	0	1	0	
Bastard limestone band	0	0	1	
Red metal	0	0	7	
Bastard limestone band	0	0	1	
Red metal	0	0	7	
Bastard limestone band	0	0	1	
Red metal	0	0	6	
Bastard limestone band	0	0	1	
Red metal	0	0	6	
Limestone balls	0	0	2	

	Yds.	Ft.	In.	
Red metal	0	0	8	
Limestone	0	0	1	
Red metal with limestone balls	1	0	10	
Red ditto ditto	0	2	6	
Red ditto	3	1	6	
Blue ditto	0	0	2½	
Soft blue rock	0	0	2½	
Soft red rock	1	1	5	
Ditto	1	2	0	
Red metal	0	0	3	
Light blue ditto	0	0	0½	
Red metal	0	0	1	
Red rock	0	0	1	
Red metal	0	0	1½	
Red rock	0	0	5	
Soft red metal	0	0	6½	
Red rock	0	0	1½	
Red rock with streaks of metal	0	1	4	
White rock	0	0	11½	
Red metals	0	0	3½	
Gray rock, sandy, full of joints, yields much water	3	2	7	
Soft gray rock, mixed with bands of dark gray metals	0	1	9½	
Gray sandy rock floor or parting	2	1	0	
Ditto ditto	1	1	5	
Dark gray sandy rock, mixed with white hard pebbles and red raddle balls	5	1	10	
Hard sandy rock	1	2	10	
Dark brown metals	1	2	8	
Metals or linsey, mixed with rock bands	1	0	5	
Ditto ditto	1	1	9	
*Red metals	6	2	6	
Black bass or shale	3	0	10	
Floor or warrant, hard	1	1	1	
Gray bass or shale	0	2	0	
Black bass or shale	0	1	11	
Brown metals, mixed with ironstone balls	0	2	5	
Ditto mixed with gray rock, soft	1	1	1	
Soft gray metals	0	1	4	
Linstey, mixed with rock bands	3	0	6	
Blue metals, soft	2	0	0	
Dark metals, blackish cast	0	1	3	
Metals, lightish colour	0	2	3	
Black shale and bastard coal	0	1	8	
Warrant, dark colour	0	1	9	

Lower permian beds containing fossil plants.

	Yds.	Ft.	In.	
Linstey, mixed with rock bands	2	0	3	Carboniferous.
Soft flaggy rock	0	0	5	
Blue metals, mixed with ironstone bands or bullions	3	1	8	
Black shale	0	0	9	
Warrant, rocky	0	1	0	
White rock, strong, with bands of metal	3	0	2	
Rock, soft and shaly	0	2	8	
Strong gray metals or linstey	2	2	2	
Strong metals	1	1	3	
Coal	0	0	3	
Strong rocky warrant	1	2	3	
Light blue metals	0	2	6	
Dark rock or burr	0	1	0	
Black bassy coal	0	0	10	
Strong warrants with streaks of metal	1	0	8	

The upper part of the permian beds named in the above section, consisting of red marls and limestones, contains the usual permian fossils, consisting of shells of the genera *Schizodus*, *Bakevellia*, *Turbo*, and *Rissoa*, and a sponge of the genus *Tragos*.

The number of beds of limestone is only 26, whereas in the bore at Messrs. Kenworthy's 54 were noticed. In the latter case, most of the hard beds were put down as limestone, whilst in the former, only those which appeared to the workman to be limestone were noticed as such; and sometimes two or three beds were classed as one. In the former also several beds were enumerated containing limestone balls, which in the latter were put down as separate beds. These circumstances may, in some measure, account for the great difference in the number of beds.

In my former paper, at page 238, I alluded to the occurrence of red and variegated sandstones containing impressions of *Calamites* and *Sigillaria*, and pieces of fossil wood, which had been found in sinking the pit at the Bedford Colliery some years since; but whether these fossils belonged to the carboniferous or permian strata—as both were lying on the pit bank

mixed together—I could not undertake to speak with certainty. If, however, they belonged to the last-named strata, they were the only specimens of fossil plants that had then to my knowledge been met with in the permian beds of the north-west of England. Now, in sinking the shaft at Bedford Lodge, of the strata in which I have given full particulars above, I collected undoubted specimens of *Sigillaria*, *Lepidodendron*, and *Sternbergia*, the specific characters of which could not be distinctly recognised, *Calamites cannæformis* and *C. approximatus*, and fossil wood, both in the fine-grained sandstones and coarse conglomerates containing rounded and partly rounded pebbles of white quartz, of the size of a common marble. The fossils occurred in all the arenaceous rocks found under the red marls and limestones, and lying above the carboniferous strata. All the beds were full of nodules and patches of a soft liver-coloured clay containing iron, and most of the fossil wood was converted into that substance. The strata which contained the fossil plants I take to be permian from their geological position, as well as from the pebbly character of the beds; for, although many of the red sandstones of the upper coal-field of Lancashire doubtless contain much red oxide of iron, and red and liver-coloured nodules of clay, I never yet found a coal measure sandstone, except in the lower field, containing large quartz pebbles;—in fact, some of these beds are quite as much conglomerates as the millstone grits are, and can scarcely be distinguished from those rocks, except that they are rather more pulverulent. The men engaged in sinking did not know where the permian strata ceased and the coal measures commenced, for both strata dipped in the same direction, and nearly at the same angle.

The coal measures to a stranger would appear to pass into the overlying permian strata, but the Worsley and Astley Four Feet seam lying under unquestionably proves that the former beds, at their point of contact with the permian strata,

are 1,100 feet down in the series from the highest beds of the upper coal-field, and, therefore, really belong to the lower part of that division.

In the red metals marked with an asterisk, 6 yards, 2 feet, 6 inches in thickness, specimens of *microconchus carbonarius*, a *cypris*, and fish scales were met with; thus clearly proving that the carboniferous strata had there commenced. In fact, these strata lie a short distance above the Four Feet coal which has been already worked under the spot where the shaft was being sunk.

Irby Hall Section.

At page 262 of my former paper, a description is given of the permian beds found at Westhouse, near Ingleton. Since the time when that sketch was written, I have met with another section of permian beds, exposed in the railway cutting near Irby Hall, lying between Westhouse and Kirby Lonsdale, about three miles from each of those places.* The breccia or conglomerate is similar in appearance to that at Westhouse, is not exposed for more than about 200 yards, and is capped by a deposit of 20 feet of brownish-coloured till. Its position with regard to the underlying rocks of the district cannot be seen. It dips to the north-east at an angle of 12°, but as you proceed to the west under the railway bridge the dip increases to 25°. The rock is composed chiefly of limestone pebbles, varying from the size of a marble to that of a man's head, some being round and others angular, cemented together by a reddish-coloured clay. Besides other stones, consisting of slates, silurians, and old red sandstones, rounded pebbles of milk-white quartz, like vein quartz, are found.

* I am indebted to Mr. Hindson, of Kirby Lonsdale, for taking me to this locality, and showing me the section.

About two years ago, Sir Charles Lyell, M.A., F.R.S., when in Manchester, showed me some breccias which he had lately collected in the vicinity of the Shropshire coal-field. In these specimens was a cream-coloured limestone, somewhat resembling a common mountain limestone, except that it had a porcelain-like appearance, possessed a slightly conchoidal fracture, and contained no fossil organic remains. This rock I immediately recognised, merely from its external characters, as one of the so-called freshwater * limestones of the upper part of the coal-field, like those of Leebotwood and Uffington, near Shrewsbury; Lane End, Staffordshire; Ardwick, near Manchester; and Whiston, near Liverpool; and I then remarked that it had not travelled far, but had been derived from the neighbouring coal-field.

Now, in the specimens of limestone found in the breccia at Irby Hall, some of them have been a good deal decomposed by water containing carbonic acid gas in solution, and many of the fossil corals have been thus brought out of their matrices and exhibited in relief. The *Syringopora ramulosa* and other corals I have collected. But the most interesting specimens from this locality are some pieces of an upper carboniferous limestone, like those before mentioned, and no doubt derived from a portion of the neighbouring Black Burton coal-field, containing undoubted specimens of the *Microconchus carbonarius* and *Cypris inflata*, as well as pieces of a peculiar flinty-looking chert which I have not hitherto met with any where in the north-west of England, except at Ardwick.

The occurrence of a carboniferous rock is what might have been expected from the vicinity of the neighbouring coal-field, since the rocks of the permian breccia or conglomerate, as I

* See papers by the author On the Origin of Coal, vol. VIII. (second series), pages 157 and 185, and On some Trails and Holes found in Rocks of the Carboniberous Strata, vol. X., page 199, of the Society's Memoirs, where he gives his reasons for the marine character of the strata of the coal measures.

have before stated, generally vary with the description of the older rocks found in the immediate vicinity; but such a limestone as the porcelain-like one is at the present time no where to be met with in the Black Burton coal-field. This rock would most probably, as in the southern coal-fields of Lancashire, be found in the upper part of the formation, but as this portion of the strata has here been removed before the breccia or conglomerate was formed, these interesting fragments afford evidence of the former occurrence of a rock now no longer to be met with *in situ*, and thus supply us with another proof of the great denuding action which took place at the close of the carboniferous epoch.

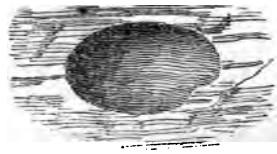
Howrigg Section.

In a geological map of the Lake Districts, published by Mr. John Ruthven, of Kendal, in 1855, a small tract of what he terms magnesian limestone is laid down. It is about two miles in extent from east to west, and lies a little south of Howrigg, near Wigton. In the month of October last I went over to Howrigg, and although I did not meet with any true permian magnesian limestone, certainly some of the mountain limestones there found might very easily be mistaken for such were it not for their fossil organic remains; and these are by no means abundant, or commonly to be met with. I, however, saw a small patch of permian breccia, and some fine-grained sandstones of a brick-red colour, containing very beautiful ripple marks, and, in their lower portions, desiccation cracks, which very much reminded me of the permian sandstones found at the Craigs, near Dumfries. Like the latter, some of the beds are so finely laminated as not only to be used for flags, but also for slating houses.

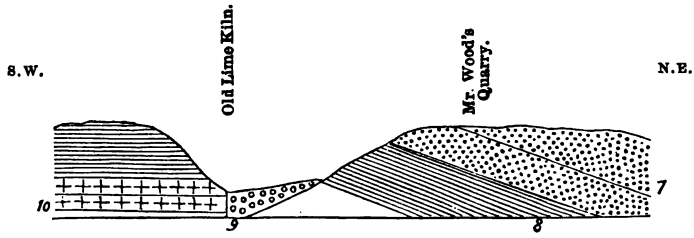
On approaching the district from Carlisle, I reached the Curthwaite station, on the Maryport railway, but saw nothing

of the strata there, owing to the thick covering of drift deposits between Curthwaite and Howrigg. On the top of the hill, near the last named place, is a small sandstone quarry, on the south side of the road. The stone there met with is laminated, of a brick-red colour, variegated with brownish tints, and divided by several red clay partings. It contains many desiccation cracks and ripple marks, and the dip of the strata is about 20° west of north, at an angle of 15°.

A little to the south of the last named place is Howrigg quarry, worked by Mr. Wood. This is an extensive excavation of fine-grained laminated sandstone, of a brick red, containing beds of a greenish-brown colour. It affords stones with many beautiful ripple marks on their surfaces, and desiccation cracks in some of the lower beds. In its lines of bedding the stone frequently shows considerable traces of black oxide of manganese, and some of the lower strata are of a greenish-brown colour, and contain nodules of greenish clay. Altogether 30 to 40 feet of stone must be exposed in the quarry. The dip of the strata is towards 20° west of north, at an angle of 15°. I looked diligently for tracks, but only saw one specimen at all likely to be taken for such, and this I unfortunately broke in attempting to cut it out with a chisel. It was a single track, and occurred in the light-coloured sandstone near the bottom of the quarry, and I traced seven impressions, each about an inch and a half apart, and one-sixth of an inch in depth, all running in nearly a straight line. The accompanying wood cut represents one of the impressions.



SHAWK SECTION.



7. Red and variegated sandstones.
8. Red and shaly marls.
9. Conglomerate.
10. Mountain limestone.

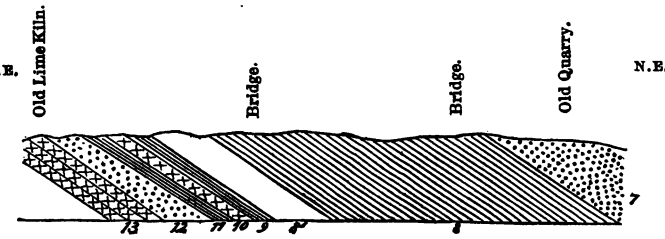
I next examined the large sandstone quarries of Mr. Wood, known by the name of the Shawk quarries, extending from Shawk Foot to the hill opposite the old lime kilns. They consist of fine-grained laminated sandstones of a brick-red colour, and contain variegated beds, desiccation cracks, and ripple marks, and in all respects resemble the Howrigg stone, before described, of which they are no doubt a continuation. The dip of the strata is to the north-east, at an angle of 15°, and probably not less than 200 to 300 feet in thickness of stone may be exposed. This sandstone is succeeded on its rise by about 140 feet of red shaly marls, dipping a little east of north, at an angle of 15°. Then comes in bottom of the valley, near the brook, but I could not trace it going under the red marls, a bed of breccia. This is composed of angular pieces of mountain limestone, cemented together by a paste of reddish clay containing more or less of red sand. It is seen below the lime kiln, near the brook side, and the beds occur in the following descending order:—.

Reddish and light-coloured sandstone.....7 feet.
Brown breccia .....4 ,,

The dip of the strata is to the south-west, at an angle of 18°. This is in the opposite direction to the dip of the sandstones and clays. Within a few yards of the breccia the mountain

limestone is quarried. It is of a cream colour, and partly crystalline. The dip, if any, is to the north-east, but it lies nearly level. Probably 30 feet in thickness of the limestone may be exposed. In it I found portions of a large *Producta*, a *Cyathophyllum*, and some crinoidal stems. Between the breccia and the mountain limestone is a fault, running from south-east to north-west, and this dislocation may have altered the inclination of the former rock, and thus caused it to appear to dip near the fault in a contrary direction to the red sandstones and clays, under which, probably, at a distance from the fault, it may dip and be conformable with. Of this, however, I at present cannot speak positively, as I have not seen the breccia underlying the red clays.

WESTWARD SECTION.



7. Red and variegated sandstone.
8. Red marls and shales.
8'. Not exposed.
9. Red marls and shales.
10. Reddish brown mountain limestone.
11. Canky stone and purple marls.
12. Purplish red sandstone.
13. Yellowish brown mountain limestone.

About a mile to the west of Howrigg is a place called Westward, and in the small brook course there is exposed a yellowish-brown limestone, partly earthy and partly crystalline in structure, very much resembling the ordinary permian magnesian limestone of Yorkshire and Durham. It has been

quarried to some extent for the purpose of making lime, but, from the quantity of unused stone left in the quarry, the attempt does not appear to have proved very successful. It dips 15° west of north, at an angle of 15°. I observed crinoidal stems in it, but no other fossils. This limestone is succeeded by a purplish-red coloured sandstone, much laminated, and containing many worm holes, similar to those of the *Arenicola carbonaria*, and some singular contorted worm coils and tracks. In all its characters this sandstone so much resembles the rock termed Smardale sandstone,* and found low down in the mountain limestone at Smardale, and in the bed of the Belah at Whitrigg, near Kirby Stephen, that I have no hesitation in pronouncing it to be of the same geological age. Then come beds of canky stone and purple-coloured marls. These are succeeded by a bed of hard limestone of a cellular structure and a reddish-brown colour, very much resembling the permian limestones of South Lancashire, and not to be distinguished from similar beds of mountain limestone found in the bed of the Belah. In this limestone I detected crinoidal stems. Next came red marls and shales, with a short distance on the bank of the stream covered up with drift, so as not to be visible. Up to this point, no doubt, the strata are carboniferous, but here commence a series of red marls, containing circular concretions of a greenish colour, with a black spot in the middle, parted by sandy beds, some of which contain ripple marks. These strata occupy the brook course between the two bridges, and exactly resemble some beds seen in the river Ayr, near Catrine, in Ayrshire, and on the beach near Methill Harbour, on the coast of Fife. Although these deposits have as yet afforded no fossil remains, I am inclined to regard them as permian rather than carboniferous. Next comes a laminated sandstone, fine-grained,

* See Professor Sedgwick's paper On the Lower Palæozoic Rocks at the base of the Carboniferous Chain between Ravenstone Dale and Ribblesdale. Quarterly Journal of the Geological Society of London, Vol. VIII., page 43.

and of a brick-red colour, dipping to the north-west at an angle of 25°. This stone I cannot distinguish from the sandstones of Howrigg and Shawk, previously described.

The beds lying between the most southerly bridge over the brook and the old lime kilns are certainly more like permian than carboniferous beds in their appearance, and might be taken for the former, as similar beds in the Belah have been by experienced geologists, if it were not for the fact that both the Westward and Belah deposits contain crinoidal stems, and other undoubted mountain limestone fossils.

The beds in this section—namely, the red marls and sandy deposits—which appear to me to belong to the permian group, dip at the same angle and in the same direction as the underlying carboniferous strata, namely, at an angle of 15°, but the red sandstone under which they disappear, although dipping in the same direction, inclines at an angle of 25°, instead of 15°.

The brick-red sandstones of Howrigg, Shawk, and Westward, with their underlying red clays, as well as the breccia at Shawk, I have little doubt will be proved to be permian. It is true that no fossil organic remains have yet been found in them, with the exception of the track alluded to in this paper; but if mineralogical characters and geological superposition are to be taken as evidence of their age, they are as good permian beds as those of Westhouse, Kirby Stephen, and Brough, in England, and Dumfries and other places in the south-west of Scotland, with the latter of which they are most probably connected.

VIII.—*The Chemical Changes which Pig Iron undergoes during its conversion into Wrought Iron.*

By F. Crace Calvert, F.C.S., M.R.A. Turin, and Mr. Richard Johnson.

[*Read March 10th*, 1857.]

Wishing to make some improvements in the manufacture of iron, we carefully examined the various analyses which had been made of pig and wrought iron, and we found that no comparison could be drawn between the results, as the samples analysed had been obtained from different sources; and also that no detailed analysis had been published of the various chemical changes which pig iron undergoes in puddling during its conversion into wrought iron. We therefore at once decided to undertake this task, with the hope of throwing some light upon this important operation. Fully to investigate the progressive and interesting chemical changes which cast iron undergoes during its conversion into wrought iron, we took samples every five or ten minutes after the pig iron had melted in the furnace. These chemical actions are clearly defined in the furnace by the peculiar appearance which the mass assumes as the operation proceeds. Before describing the various chemical changes, the appearance of the melted mass as taken out of the furnace, and its composition, we shall describe, with some detail, the analytical processes which we have adopted to determine the various elements which exist in pig and wrought iron, and in the samples taken during the puddling.

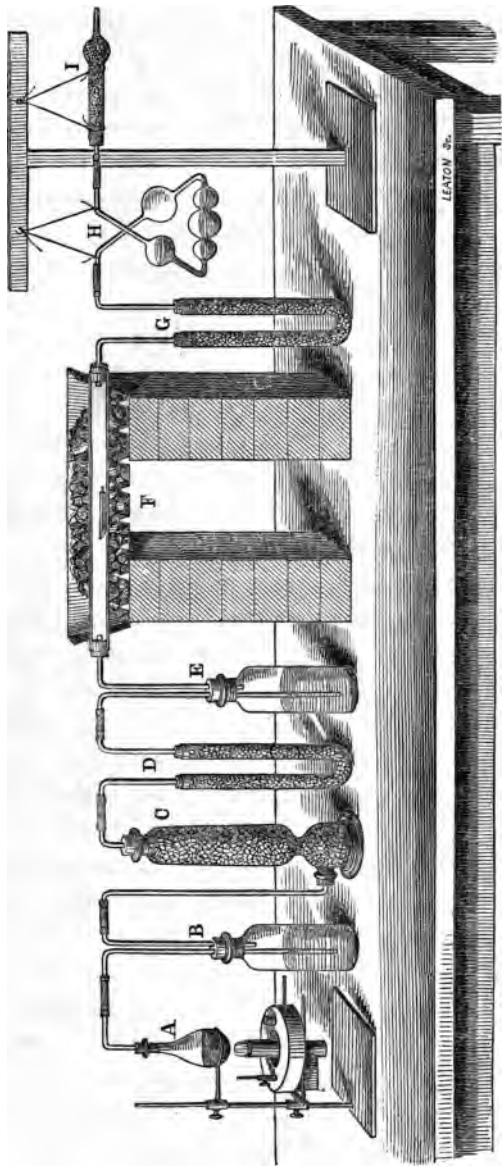
These details of analysis appear to us the more important when it is remembered that most of the heterogeneous substances existing in pig iron, are present only in minute quantities, and that it is on their gradual removal or decrease that the subsequent quality of the wrought iron depends. Also, it is necessary to bear in mind, that we had to trust entirely to the exactitude of the analytical methods adopted to appreciate the chemical changes which gradually took place in the melted mass during the hour and a quarter that the conversion of the cast into wrought iron lasted.

Iron.

The quantity of iron was determined by dissolving one gramme of iron in pure hydrochloric acid, reducing the solution to a perfect protosalt by a little pure zinc, and then determining the amount of iron by Margueritte's process.

Carbon.

To determine this element we found, after many trials, that the best process was to reduce the iron into very fine powder, either by pulverization or by means of a file, and then to burn the carbon under the influence of a red heat by a slow current of pure and dry oxygen gas. The apparatus which we used was the following:—



A. A flask containing a mixture of chlorate of potash and oxide of copper, which by gently heating gave off a regular current of oxygen.

B. A bottle containing a concentrated solution of caustic potash, so as to retain any chlorine or any oxygenated compound of this gas, which might be produced.

C. A tube full of pumicestone moistened with solution of caustic potash, and employed with the same view as the last.

D. A U tube filled with pieces of solid melted caustic potash, also used for the same purpose.

E. A bottle containing sulphuric acid, for retaining any moisture which might accompany the oxygen gas.

F. A porcelain tube in which was placed a small porcelain dish containing the pulverized cast iron.

G. A tube filled with small pieces of pumicestone moistened with sulphuric acid, with the view of retaining any moisture.

H. A Liebig tube full of a concentrated solution of caustic potash, to determine the amount of carbonic acid produced by the combination of the oxygen with the carbon of the cast iron.

I. A small tube with fragments of caustic potash, to retain any trace of carbonic acid which might not be absorbed in the Liebig tube.

To render the absorption of the carbonic acid complete, it is necessary to conduct the operation very regularly and

slowly; therefore, about two hours are required to burn all the carbon existing in about three grammes of cast iron. By this method, two analyses of the same sample seldom presented a greater difference than 0.005. We also always took the precaution to dissolve the oxide of iron obtained, after combustion, in order to see that no hydrogen was given off and consequently no metallic iron remained.

Silicium.

There is considerable difficulty in determining with precision this element in pig iron, and it was only after several fruitless trials of various processes that we adopted the following, which gave us very satisfactory and concordant results.

Five grammes of pig iron were dissolved in aqua regia containing excess of nitric acid, the whole was then evaporated to dryness and fused in a platinum crucible with three times its weight of a mixture of pure carbonate of potash and carbonate of soda. The mass obtained was dissolved in water and boiled with aqua regia until the whole of the peroxide of iron had entered into solution, and then was evaporated a second time to dryness and heated carefully to about 200° C. The mass was then heated with hydrochloric acid and water, and the silica, on being gathered on a filter, was washed with dilute hydrochloric acid until it was perfectly white; it was then dried, and calcined, and its weight gave the amount of silicium in the iron analysed.

Sulphur.

In consequence of the small proportion in which this element exists in pig and wrought iron, considerable difficulty is experienced in ascertaining with accuracy the various proportions of sulphur existing in iron; and this difficulty was increased by the fact that none of the methods recommended gave satisfactory results in our hands. Thus, for example, the method which consists in determining the sul-

phur in the state of sulphuretted hydrogen failed, owing to the difficulty of removing the last traces of sulphuretted hydrogen held in solution in the liquid in which the iron is dissolved and in which the gas is produced. As to the process which consists in dissolving the iron in aqua regia and boiling off the greatest part of the acid and then adding nitrate of baryta to the solution, it cannot be followed with security, for one of us has shown that sulphate of baryta is soluble in acid liquors, especially in those containing nitric acid, and often in such quantities as to make a greater difference between the analyses of two samples of the same iron than the real difference which exists in two samples of iron from different ores.

These considerations induced us to modify the last mentioned process in the following way. Five grammes of the sample of iron to be analysed were reduced to fine powder and gradually and slowly added to a strongly oxydizing aqua regia, composed of four parts of fuming nitric acid and one part of hydrochloric acid. The iron being dissolved, the solution was evaporated to the consistence of a thin syrup, and then gradually mixed with four times its weight of a mixture of pure carbonates of potash and soda, and heated to redness for one hour in a platinum crucible. The fused mass was then heated with boiling water until all the soluble portion was dissolved. This liquor was then rendered slightly acid with hydrochloric acid, evaporated to dryness, and heated at 200° C., to render the silica insoluble. The whole was then heated by water slightly acidulated with acetic acid, and on the silica being separated by filtration, the amount of sulphate, and consequently, of sulphur, was determined, from the weight of sulphate of baryta obtained.

Phosphorus.

We also attached great importance to the exact valuation of this body, because, like sulphur, its presence even in small

quantities is most injurious, the more so as such minute quantities as a few thousandths more or less will completely alter the value of this metal for many uses. To determine phosphorus, the process which we followed was similar to that employed for the sulphur, with this difference, that we added to the liquid from which we had separated the silica, a little hydrochloric acid, and then ammonia in excess, instead of acetic acid, as we had done in the analysis for sulphur. The liquid was allowed to stand to see if any alumina separated, and if not, we added hydrochloric acid in excess, then pure chloride of calcium and then ammonia again, when phosphate of lime, having the following formula $P0_5 3Ca0$, was precipitated, from which the quantity of phosphorus was calculated. We always took care to operate on such a bulk of fluid as to prevent the precipitation of any sulphate of lime, and we also washed rapidly to prevent any carbonate of lime being formed. We verified this method several times during our analyses, by determining the amount of lime in our precipitates and the amount of phosphoric acid by M. Reynoso's process.

Aluminum.

If there was any alumina it was separated during the last process, and its amount determined.

We also made several fusions of iron dissolved in aqua regia, and evaporated with a mixture of alkaline carbonates to which we had added a little caustic alkali and we found no alumina or mere traces in the iron analysed by us.

Manganese.

Five grammes of iron were dissolved in aqua regia, and the whole evaporated to dryness and calcined with alkaline carbonates. The fused mass was treated with boiling water, and to the solution were added small pieces of Swedish paper, to reduce the manganese.

The iron and manganese were then collected on a filter, well washed, and then dissolved in hydrochloric acid. This solution was again evaporated, and heated so as to render the silicic acid insoluble.

The residue was then heated with weak hydrochloric acid, and the solution filtered to separate the silica; carbonate of baryta, recently prepared, was then added to precipitate the oxide of iron; this was separated by filtration, sulphate of soda and a little hydrochloric acid were added to the liquid, to separate the baryta in solution, and finally the manganese was precipitated by a little caustic potash, washed, dried, calcined, and its amount ascertained.

It is necessary that we should describe, in a rapid manner, the physical conditions which pig iron assumes during its conversion. When first melted in a puddling furnace it forms a thick pasty mass, which gradually becomes thin and as fluid as mercury. When it has reached this point it experiences a violent agitation, technically called "the boil," which is produced, no doubt, by the oxidation of the carbon and the escape of the carbonic oxide then generated. During this period of the operation the mass swells to several times its primitive bulk, and the puddler quickly agitates the melted mass to facilitate the oxidation of the carbon. After a short time the mass gradually subsides, the puddler then changes his tool and takes the "puddle" to gather with it the granules of malleable iron floating in the melted mass of scoria or slag. The granules or globules of iron gradually weld together and separate from the scoria, and this separation is hastened by the puddler gradually forming large masses, called balls, weighing from 70 to 80 lbs., from which the scoria drains out.

This part of the operation requires great skill, as nearly the whole of the carbon has been oxidized, so that if the

current of air is not managed with great care the iron itself is oxidized, or, as it is technically termed, "burnt;" and thus not only does great loss ensue in the quantity of malleable iron produced, but also the iron containing a certain quantity of oxide of iron is brittle and of bad quality.

We shall now examine the various chemical changes which pig iron undergoes during its conversion into wrought iron.

The iron we took for our experiments was a good cold blast Staffordshire iron, the pig was rather grey, being of the quality used for making iron wire, or a grey No. 3. Its composition was as follows:—

	First Analysis.	Second Analysis.	Mean.
Carbon	2.320	2.230	2.275
Silicium	2.770	2.670	2.720
Phosphorus	0.580	0.710	0.645
Sulphur	0.318	0.288	0.301
Manganese and Aluminum	Traces	...	...
Iron	94.059	94.059	94.059
	100.047	99.957	100.000

First Sample, taken out of the furnace at 12 40 p.m.

Two hundred and twenty-four pounds of the above pig iron were introduced at twelve o'clock, on the 14th of April, 1856, into a puddling furnace, which had been cleaned out with wrought iron scraps. After 30 minutes the pigs began to soften and to be easily crumbled, and 10 minutes more had hardly elapsed when they entered into fusion. A sample was immediately taken out from the centre of the melted mass, with a large iron ladle, and poured on a stone flag to cool. The flue of the furnace, which had hitherto been kept open, was now nearly closed by a damper at the top of the chimney, so that the products of combustion came out by the door of the furnace and other openings, whilst little or none escaped by the chimney.

APPEARANCE OF THE SAMPLE.—On breaking the sample as taken out of the furnace, it had no longer the appearance of grey No. 3 pig iron, but had a white, silvery, metallic fracture, similar to that of refined metal. The rapid cooling of the sample was, no doubt, the cause of the change noticed, for it contained quite as much carbon as the pig iron used; and, further, the carbon was in a very similar condition, as in both cases a large quantity of black flakes of carbon floated in the acid liquors in which the iron was dissolved. The following is the amount of carbon and silicium which the above sample contained per cent.

	First Analysis.	Second Analysis.	Mean.
Carbon	2.673	2.780	2.726
Silicium	0.893	0.938	0.915

These results are highly interesting, as they show that the iron had undergone, during the 40 minutes which it had been in the furnace, two opposite chemical changes; for, whilst the proportion of carbon had increased, the quantity of silicium had rapidly decreased.

This curious fact is still further brought out by the sample which we took out of the furnace at 1 p.m., or 20 minutes later than the last sample analysed, as is shown in this table.

	Carbon.	Silicium.
Pig Iron used	2.275	2.720
First Sample taken out at 12.40	2.726	0.915
Second Sample taken out at 1 p.m.	2.905	0.197

Therefore the carbon had increased 0.630 or 21.5 of its own weight, and the silicium had decreased in the enormous proportion of above 90 per cent. It is probable that these opposite chemical actions are due, in the case of the carbon, to the excess of this element in a state of minute division, or in a nascent state, in the furnace, and that under the influence of the high temperature it combines with the iron, for

which it has a great affinity; whilst the silicium and a small portion of iron are oxidized and combined together to form protosilicate of iron, of which the scoria or slag produced during this first stage of puddling consists, and which plays such an important part in the remaining phenomena of the puddling process.

SECOND SAMPLE, taken out at 1 p.m.

This sample contained the following quantities of carbon and silicium.

	First Analysis.	Second Analysis.	Mean.
Carbon	2.910	2.900	2.905
Silicium	0.226	0.168	0.197

It had the same white silvery appearance as No. 1, but with this difference, that it was slightly malleable under the hammer, instead of being brittle like No. 1. The scoria also is on the upper surface of the mass when cold, and not mixed with the metallic iron as in preceding samples.

THIRD SAMPLE, taken out of the furnace at 1 5 p.m.

The mass in the furnace having become very fluid and beginning to swell or enter into the state called "the boil," a small quantity was ladled out. The appearance of the sample when cold was quite different from that of the two previous ones, being composed of small globules adhering to each other and mixed with the scoria; the mass therefore was not compact like the former ones, but was light and spongy, its external appearance was black, and the small globules, when broken, presented a bright metallic lustre, and were very brittle under the hammer.

We had, for some time, considerable difficulty in separating the scoria from the globules of iron, but we found that by pulverizing the whole for a long time, the scoria was reduced to impalpable powder, and by sieving we could separate it

from the iron, which was much less friable. The iron thus cleansed from its scoria gave us the following results:—

	First Analysis.	Second Analysis.	Mean.
Carbon	2.466	2.421	2.444
Silicium	0.188	0.200	0.194

FOURTH SAMPLE, taken at 1 20 p.m.

As soon as the last sample had been taken out the damper of the furnace was slightly raised, so as to admit a gentle current of air, which did away with the smoke which had been issuing from the puddler's door, and a clear and bright flame was the result. This was done, no doubt, to facilitate the oxidation of the carbon of the iron, and to increase this action the puddler quickly agitated the mass. Under these two actions the mass swelled up rapidly, and increased to at least four or five times its original bulk, and at 1 20 p.m., the mass being in full boil, this fourth sample was taken out. Whilst cooling, it presented the interesting fact, that in various parts of it small blue flames of oxide of carbon were perceived, no doubt arising from the combustion of carbon by the oxygen of the atmosphere.

It is curious that this phenomenon was not observed in the previous samples. It is due probably to the following causes: Firstly, that the pig iron having been brought by the boil to a state of minute division, offers a large surface to the action of the oxygen of the air, and thus the combination of the oxygen with the carbon of the iron is facilitated. And secondly, that at this period the carbon seems to possess little or no affinity for the iron, for one of us has often observed, that when pig iron rich in graphite is puddled, the carbon is liberated from the iron; for if a cold iron rod is plunged into the mass of melted iron in the puddling furnace, it is covered with iron and abundant shining scales of graphite carbon.

The appearance of this, No. 4 sample, was very interesting; and the best idea that we can give of it is, that it is

so light and formed of such minute granules, as to be exactly like an ant's nest. The particles have no adherence to each other, for by mere handling of the mass it falls into pieces. This is due to each particle of iron being intimately mixed with scoria.

The granules of iron have a black appearance externally, are very brittle under the hammer, and when broken present a bright silvery metallic fracture.

The scoria was separated by the method above described for No. 3, and the quantities of carbon and silicium which the iron contained were as follows:—

	First Analysis.	Second Analysis.	Mean.
Carbon	2.335	2.276	2.305
Silicium	0.187	0.178	0.182

FIFTH SAMPLE, taken at 1 35 p.m.

This sample is a most important one in the series, as it is the first in which the iron is malleable and flattens when hammered. It was ladled out of the furnace just as the boil was completed and the swollen mass began to subside. The damper at the top of the chimney was drawn up, so that a very rapid draught was established through the furnace. The puddler also changed his tool, leaving the rubble and taking the puddle to work with.

When cold it partakes of the appearance of Nos. 3 and 4 samples, the mass being spongy and brittle as in No. 4, but less granulated, and like No. 3 being in separate globules, mixed with the scoria. The granules are black externally, but are bright and metallic when flattened. The analysis of these globules proves that the mass of iron in the furnace has lost, during the quarter of an hour which has elapsed since the taking of No. 4 sample, a large proportion of its carbon equal to 20 per cent. of its weight, whilst the silicium on the contrary has remained nearly stationary.

	First Analysis.	Second Analysis.	Mean.
Carbon	1.614	1.681	1.647
Silicium	0.188	0.178	0.185

SIXTH SAMPLE, taken at 1 40 p.m.

The reason why this sample was taken only five minutes after the last sample, was that the mass in the furnace was rapidly transforming itself into two distinct products, viz., the scoria on the one hand and small globules of malleable iron on the other. We attached some importance to this sample, as the workman was on the point of beginning the balling or agglommerating the globules of iron, so as to form large balls of about 80 lbs. weight to be hammered and rolled out into bars. Whilst the mass taken out for analysis was cooling, small blue flames of oxide of carbon issued from it. These were similar to those observed in Nos. 4 and 5, but were not so abundant.

The appearance of this sample was similar to the last one, with the exception that the scoria was not so intimately mixed with the globules of iron, and that these were larger and slightly welded together when hammered. The proportions of carbon and silicium were as follows :—

	First Analysis.	Second Analysis.	Mean.
Carbon	1.253	1.160	1.206
Silicium	0.167	0.160	0.163

When these figures are compared with those of the previous analysis, it is interesting to observe that whilst the silicium remains nearly stationary the carbon rapidly diminishes, for in the five minutes which elapsed between the taking out of the two samples, there are 28 per cent. of the carbon burnt out. This rapid decrease of carbon in the iron is maintained during the remaining ten minutes of puddling. In fact, in one quarter of an hour, viz., from 1 35 to 1 50 the iron lost 50 per cent. of the carbon.

SEVENTH SAMPLE, taken at 1 45 p.m.

This sample was obtained when the puddler had begun to ball. The appearance of the sample, although similar to the

last, differs from it by the granules being rather larger and nearly separated from the scoria, which forms a layer at the top and bottom of the mass.

These granules are also much more malleable, for they are easily flattened under the hammer. This last fact is easily accounted for by the small amount of carbon which it contains, as stated above and shewn by these results.

	First Analysis.	Second Analysis.	Mean.
Carbon	1.000	0.927	0.963
Silicium	0.160	0.167	0.163

EIGHTH SAMPLE, taken 1 50 p.m.

This last sample was taken a few minutes before the balls were ready to be taken out of the furnace to be placed under the hammer, and was a part of one of the balls which was separated and placed to cool.

It was observed that no blue flame issued from the mass as it cooled. The appearance of the sample shewed that the mass constituting the ball was still spongy and granulated, similar to the previous ones. The only difference was that the granules adhered together sufficiently to require a certain amount of force to separate one from the other, and also that they were much more malleable under the hammer. They were found to contain the following quantities of carbon and silicium, per cent.:—

	First Analysis.	Second Analysis.	Mean.
Carbon	0.771	0.773	0.772
Silicium	0.170	0.167	0.168

We should observe here that the black coating which covers the granules of iron, even of No. 8 sample, preserves the iron from all oxidation, for none of the samples became oxidized during the nine months they were in the laboratory exposed to the atmosphere, and to the various acid fumes floating about. This black coating is probably composed of a saline oxide of iron.

Ninth Sample of Puddled Bar.

The balls taken out of the furnace were hammered and then rolled into bars, and in these we found the following:—

	First Analysis.	Second Analysis.	Mean.
Carbon	0.291	0.301	0.300
Silicium	0.130	0.110	0.120
Sulphur	0.142	0.126	0.134
Phosphorus	0.139	...	0.139

Tenth Sample—Wire Iron.

The puddled bars were cut into billets of about four feet in length, and heated in a furnace to white heat, and then rolled into wire iron. The proportions of carbon, silicium, sulphur, and phosphorus, were as follows:—

	First Analysis.	Second Analysis.	Mean.
Carbon	0.100	0.122	0.111
Silicium	0.095	0.082	0.088
Sulphur	0.093	0.096	0.094
Phosphorus	0.117	...	0.117

To complete the series of products in the conversion of pig iron into wrought iron, we analysed the scoria or slag which remained in the furnace after the balls had been taken out, and found its composition to be as follows:—

Silica	16.53
Protoxide of Iron	66.23
Sulphuret of Iron	6.80
Phosphoric Acid	3.80
Protoxide of Manganese	4.90
Alumina	1.04
Lime	0.70
	100.00

Therefore, in the scoria are found the silicium, phosphorus, sulphur, and manganese, which existed in the pig iron; and probably the phosphorus and silicium are removed from the iron by their forming fusible compounds with its oxide.

We shall conclude this paper by giving our results in a tabulated form, so that the removal of the carbon and silicium

of the Manchester Memoirs will be found most easily applicable.

It will at least be interesting, for a comparison of methods, to show how very easily the 7-partitions of X can be obtained by my method, which requires no expansions, transformations, or summations of any kind, nor anything more than very simple eliminations. Nor has the formula for the 7-partitions, so far as I know, been explicitly found by any one.

That for the 6-partitions was first given by me at p. 143 of the twelfth volume of the Manchester Memoirs, as follows:

$$
\begin{aligned}
{}_6P_x = \frac{1}{60^2.12^2}\Big\{ & 6x^5+135x^4+760x^3-5046x \\
(P) \qquad & -(1350x^2+5400x)*2_{x-1} \\
& +7926x\cdot *6_x - 8424x(*6_{x-1}+*6_{x-5}) \\
& +1176x\cdot *6_{x-3} - 1674x(*6_{x-2}+*6_{x-4}) \\
+*6_x\ & (-47556k \qquad +180(d_5+d_{11}+d_{17}+ \text{ . . to } k \text{ terms})) \\
+*6_{x-1}& (+50544k-31225+180(d_0+d_6+d_{12}+ \text{ . . to } k \text{ terms})) \\
+*6_{x-2}& (+10044k- 6656+180(d_1+d_7+d_{13}+ \text{ . . to } k \text{ terms})) \\
+*6_{x-3}& (- 7056k- 4617+180(d_2+d_8+d_{14}+ \text{ . . to } k \text{ terms})) \\
+*6_{x-4}& (+10044k- 9328+180(d_3+d_9+d_{15}+ \text{ . . to } k \text{ terms})) \\
+*6_{x-5}& (+50544k-16889+180(d_4+d_{10}+d_{16}+ \text{ . . to } k \text{ terms}))\Big\};
\end{aligned}
$$

where $x=60h+6(k-1)+c$; $(c\gtrless 0, \angle 7)$;

$=60h+p+1$; $(k\gtrless 0, \angle 10)$;

and $\frac{d_p}{2880}$ is the co-efficient of the circulator $*60_{x-p}$ in ${}_5P_x$.

In the expression given at p. 143 above quoted, the constant $*2_{x-1}C'+F$ is by inadvertence omitted, which stands at the top of p. 142; and at line 13, p. 143, there is a misprint of -3598 for -3528. The omission of the constant $*2_{x-1}C'+F$ makes no difference in the value of ${}_6P_x$, because that value is always the integer nearest, whether over or under, to the sum of the terms in x.

The 60 numbers d_p, are given at p. 139 of the Memoirs quoted above. It is not necessary for our purpose here to

refer to them, except for the remark, which inspection of that page will verify, that

$$d_0+d_1+d_2+d_3+d_4+d_5=91,$$
$$d_{30}+d_{31}+d_{32}+d_{33}+d_{34}+d_{35}=91,$$

the sums of the first and sixth horizontal lines; and that the sum of the six numbers in every other horizontal line at p. 139, beginning with d_6, d_{12}, d_{18}, d_{24}, d_{36}, d_{42}, d_{48}, and d_{54}, is always $= -485$. These horizontal lines appear as vertical lines in the formula for ${}_6P_x$ just written.

The constant circulator, or term free from x, is obtained from the above formula by giving to k its 10 successive values, 0, 1, 2 . . . 9. As both the sum of the 60 elements of that term and the elements themselves are required, the first for the determination of the terms in x of ${}_7P_x$, and the latter for that of the circulating constant in it, we must here obtain these data, before attempting to find ${}_7P_x$.

Adding up the six concluding lines of the formula above written, we obtain

$$\frac{1}{720^2}\left\{66564k-68715k^0+180(s_0+s_6+s_{12}+\text{ . . . to } k \text{ terms})\right\};$$

where $s_p=d_p+d_{p+1}+$ . . . to 6 terms,

$$s_0=s_{30}=91, \text{ and}$$

s_6, s_{12}, s_{18}, s_{24}, s_{36}, s_{42}, s_{48}, are each equal -485.

Giving to k all its values, we have the sum

$$\frac{1}{720^2}\left\{66564\cdot45-68715\cdot10+180\begin{pmatrix}9s_0+8s_6+7s_{12}+6s_{18}+5s_{24}\\+4s_{30}+3s_{36}+2s_{42}+s_{48}\end{pmatrix}\right\}$$
$$=\frac{1}{720^2}\left\{299538-687150+180(13\cdot91-32\cdot485)\right\},$$
$$=-\frac{272430}{720^2}=\frac{1}{720^2}(f_0+f_1+f_2+\text{ . . . }+f_{59}),$$

the sum of the 60 elements of the circulating constant, whose form is $\Sigma f_p{}^*60_{x-p}\cdot\frac{1}{720^2}$.

If it could be proved true for ${}_7P_x$, as it is for all the lower partitions of x, that the sum of the terms in x expressed the number of the partitions, this sum just found, together with

the terms in x of ${}_6P_x$, would easily give us ${}_7P_x$; for they give us, as we shall see, very readily all the terms in x of ${}_7P_x$. But as this does not appear certainly true, it becomes necessary to write out in full the constant term of ${}_6P_x$, that we have it in our power accurately to express the constant of ${}_7P_x$, which, unlike this of ${}_6P_x$, we may find essential to the value.

This constant is, writing the numerators f_1, f_8, &c.,

$f_1 =$ 19319	$f_2 =$ — 5008	$f_3 =$ 7047	$f_4 =$ —62464
$f_8 =$ —48128	$f_9 =$ — 46089	$f_{10} =$ —50800	$f_{11} =$ 45319
$f_{15} =$ —34425	$f_{16} =$ —256	$f_{17} =$ — 7817	$f_{18} =$ 73872
$f_{22} =$ 11408	$f_{23} =$ 3847	$f_{24} =$ 20736	$f_{25} =$ —63625
$f_{29} =$ —49289	$f_{30} =$ 32400	$f_{31} =$ 51719	$f_{32} =$ —27392
$f_{36} =$ 82944	$f_{37} =$ —1417	$f_{38} =$ —15728	$f_{39} =$ —13689
$f_{43} =$ 10247	$f_{44} =$ — 68864	$f_{45} =$ —66825	$f_{46} =$ 32144
$f_{50} =$ —57200	$f_{51} =$ 48519	$f_{52} =$ —20992	$f_{53} =$ —28553
$f_{57} =$ — 4617	$f_{58} =$ —9328	$f_{59} =$ —16889	$f_{60} =$ 0

$f_5 =$ —70025	$f_6 =$ 115344	$f_7 =$ 30983
$f_{12} =$ 62208	$f_{13} =$ — 22153	$f_{14} =$ —36464
$f_{19} =$ —10489	$f_{20} =$ — 89600	$f_{21} =$ 16119
$f_{26} =$ 25744	$f_{27} =$ 27783	$f_{28} =$ —41728
$f_{33} =$ —25353	$f_{34} =$ — 30064	$f_{35} =$ —37625
$f_{40} =$ —83200	$f_{41} =$ 12919	$f_{42} =$ 94608
$f_{47} =$ 24583	$f_{48} =$ 41472	$f_{49} =$ —42889
$f_{54} =$ 53136	$f_{55} =$ — 31225	$f_{56} =$ — 6656

These numbers can all be obtained from $f_{60}=0$, $f_{59}=-16889$, $f_{58}=-9328$, $f_{57}=-4617$, $f_{56}=-6656$, and $f_{55}=-31225$, by the formula

$$f_{p+6}-f_p = 11664(12_{x-2}+12_{x-3}+12_{x-6}+12_{x-7}+12_{x-10}+12_{x-11}) \times(1-20_{x-6}-20_{x-11}) -53136(12_x+12_{x-1}+12_{x-4}+12_{x-5}+12_{x-8}+12_{x-9}) \times(1-20_{x-1}-20_{x-16}) +115344.(20_{x-6}+20_{x-11})+50544.(20_{x-1}+20_{x-16}).$$

And it is remarkable, that

$$f_{p+30}-f_p = \pm 180^2.$$

The reason of all this may be found in the fact, that the elements d_p of the circulating constant in ${}_5P_x$ all satisfy, except only twelve of them,

$$d_{p+1}=d_{p-1};$$

while all of them satisfy

$$d_{p+30}-d_p=\pm 360.$$

We proceed to deduce from the expression for ${}_6P_x$, that for ${}_7P_x$, the 7-partitions of x.

I have suffered no little perplexity in the endeavour to obtain ${}_7P_x$ from the consideration of the equation

$${}_kP_x-{}_kP_{x-k}={}_{k-1}P_{x-1},$$

which gave me readily my previous results. But all difficulty disappears if we use the two equations

$${}_7P_x-{}_7P_{x-7}={}_6P_{x-1}, \text{ and}$$

$${}_7P_x-{}_7P_{x-42}={}_6P_{x-1}+{}_6P_{x-8}+\ldots+{}_6P_{x-36},$$

which follow easily from the fundamental theorem

$${}_kP_x={}_{k-1}P_{x-1}+{}_{k-1}P_{x-k-1}+{}_{k-1}P_{x-2k-1}+\ldots, \text{ or,}$$

writing $x=7(c-1)+c$, $(c\nearrow 0, \angle 8)$,

$${}_7P_x={}_6P_{x-1}+{}_6P_{x-8}+{}_6P_{x-15}+\ldots+{}_6P_{c-1}. \quad \text{(A.)}$$

Let $({}_7P_x)$ stand for the sum of the algebraic, or non-circulating terms in the right member of equation (A), and $({}_7P_{x-7})$ for the sum of such terms in

$${}_7P_{x-7}={}_6P_{x-8}+{}_6P_{x-15}+\ldots+{}_6P_{c-1}. \quad \text{(A')}$$

It is plain that, if $[{}_6P_{x-1}]$ represent the non-circulating part of ${}_6P_{x-1}$, we shall have

$$({}_7P_x)-({}_7P_{x-7})=[{}_6P_{x-1}]. \qquad \text{(B)}$$

Let then

$$({}_7P_x)=Ax^6+Bx^5+Cx^4+Dx^3+Ex^2+Fx+Gx;$$

for evidently no power above the 6th can disappear by the above subtraction. Then (B) is

$$A\left(x^6-(x-7)^6\right)+B\left(x^5-(x-7)^5\right)+C\left(x^4-(x-7)^4\right)+D\left(x^3-(x-7)^3\right)$$
$$+E\left(x^2-(x-7)^2\right)+F\left(x-(x-7)\right)$$
$$=\frac{1}{(720)^2}\left\{6(x-1)^5+135(x-1)^4+760(x-1)^3-5046(x-1)\right\}$$

In this subtraction the constant G_x must vanish of course, if it be an ordinary constant; and if it be a circulator, it can depend only on the 7 values of c in equation (A); that is, it must be of the form

$$G_1{}^*7_{x-1}+G_2{}^*7_{x-2}+\ \ .\ \ .\ \ .\ \ +G_0{}^*7_x,$$

so that $G_x=G_{x-7}$, and can have only seven values.

Equating the co-efficients of powers of x, we have

$$42A=\frac{6}{720^2},\ \therefore A=\frac{1}{7\cdot720^2};$$

$$-15\cdot7^2A+35B=\frac{105}{720^2},\ \therefore B=\frac{6}{720^2};$$

$$20\cdot7^3A-10\cdot7^2B+4\cdot7C=\frac{280}{720^2},\ \therefore C=\frac{80}{720^2};$$

$$-15\cdot7^4A+10\cdot7^3B-6\cdot7^2C+3\cdot7D=-\frac{1530}{720^2},\ \therefore D=\frac{2185}{7\cdot720^2};$$

$$6\cdot7^5A-5\cdot7^4B+4\cdot7^3C-3\cdot7^2D+27E=-\frac{3276}{720^2},\ \therefore E=-\frac{1361}{2\cdot720^2};$$

$$-7^6A+7^5B-7^4C+7^3D-7^2E+7F=\frac{4415}{720^2},\ \therefore F=-\frac{55899}{14\cdot720^2}.$$

Wherefore

$$({}_7P_x)=\frac{x^6}{7\cdot720^2}+\frac{6x^5}{720^2}+\frac{80x^4}{720^2}+\frac{2185x^3}{7\cdot720^2}-\frac{1361x^2}{2\cdot720^2}-\frac{55899x}{14\cdot720^2}+G_x.$$

The value of the constant G_x is obtained from the equation, (putting $x=7(1-1)+c$)

$$({}_7P_c)=({}_7P_{c-7})+[{}_6P_{c-1}]=[{}_6P_{c-1}],$$

for ${}_7P_{x-7}$ has no terms at all on the right of equation (A′), if $x\angle8$; *i.e.*, $({}_7P_{c-7})=0$. This constant therefore will be a circulator of the form $\Sigma G_m{}^*7_{x-m}$.

The value of G_7 is readily found by the equation

$$({}_7P_0)=({}_7P_{0-7})+[{}_6P_{0-1}]=0=G_7;$$

for $x=0$, which requires $e=0$, $c=7$, makes every term on the right of equation (A) vanish. The remaining six values, or all the seven, are obtained by putting for c its successive values in

$$({}_7P_c)=[{}_6P_{c-1}],$$

which is

$$\frac{c^6}{7.720^2}+\frac{6.c^5}{720^2}+\frac{80c^4}{720^2}+\frac{2185.c^3}{7.720^2}-\frac{1361c^2}{2.720^2}-\frac{55899c}{14.720^2}+G_c$$
$$=\frac{1}{720^2}\left\{6(c-1)^5+135(c-1)^4+760(c-1)^3-5046(c-1)\right\}.$$

Let now $({}_7P_x)'$ stand for the sum of the circulating terms in x on the right of equation A; and $[{}_6P_{x-1}]'$ for the like terms of ${}_6P_{x-1}$. Then evidently

$$({}_7P_x)'-({}_7P_{x-42})'=[{}_6P_{x-1}]'+[{}_6P_{x-8}]'+\ldots+[{}_6P_{x-36}]'; \quad (C)$$

for if we put in (A) $x-42$ for x, and subtract the result from (A), the remainder on the right must be the terms here presented. And it is plain that no power of x higher than the third can have disappeared on the right of (C) by the subtraction. Let

$$({}_7P_x)'=ax^3+bx^2+cx+d_x; \quad (c)$$

then (C) becomes

$$a\left(x^3-(x-42)^3\right)+b\left(x^2-x-42)^2\right)+c\left(x-(x-42)\right) =$$
$$\frac{1}{720^2}\Big\{\left(-1350(x-1)^2-5400(x-1)\right)2_{x-2}+\left(-1350(x-8)^2\right.$$
$$\left.-5400(x-8)\right)2_{x-9}$$
$$+\left(-1350(x-15)^2-5400(x-15)\right)2_{x-16}+\left(-1350(x-22)^2\right.$$
$$\left.-5400(x-22)\right)2_{x-23}$$
$$+\left(-1350(x-29)^2-5400(x-29)\right)2_{x-30}+\left(-1350(x-36)^2\right.$$
$$\left.-5400(x-36)\right)2_{x-37}$$
$$+(x-1)(+7926\cdot6_{x-1}-8424\cdot6_{x-2}-1674\cdot6_{x-3}+1176\cdot6_{x-4}$$
$$-1674\cdot6_{x-5}-8424\cdot6_{x-6})$$
$$+(x-8)(-8424\cdot6_{x-13}+7926\cdot6_{x-8}-8424\cdot6_{x-9}-1674\cdot6_{x-10}$$
$$+1176\cdot6_{x-11}-1674\cdot6_{x-12})$$
$$+(x-15)(-1674\cdot6_{x-19}-8424\cdot6_{x-20}+7926\cdot6_{x-15}-8424\cdot6_{x-16}$$
$$-1674\cdot6_{x-17}+1176\cdot6_{x-18})$$
$$+(x-22)(+1176\cdot6_{x-25}-1674\cdot6_{x-26}-8424\cdot6_{x-27}+7926\cdot6_{x-22}$$
$$-8424\cdot6_{x-23}-1674\cdot6_{x-24})$$
$$+(x-29)(-1674\cdot6_{x-31}+1176\cdot6_{x-32}-1674\cdot6_{x-33}-8424\cdot6_{x-34}$$
$$+7926\cdot6_{x-29}-8424\cdot6_{x-30}$$
$$+(x-36)(-8424\cdot6_{x-37}-1674\cdot6_{x-38}+1176\cdot6_{x-39}-1674\cdot6_{x-40}$$
$$-8424\cdot6_{x-41}+7926\cdot6_{x-36})\Big\}$$

The constant d_x must disappear in this subtraction (C); for if it be a circulator, it can depend only on the value of c in equation (A) combined with the circulators in $[{}_6P_x]'$; that is, it can have only 42 values, and d_x must be the same with d_{x-42}.

The circulators 2_{x-2}, 2_{x-16}, &c., 6_{x-1}, 6_{x-13}, &c., standing vertically under each other, are equal, if $x>40$; supposing then that $x=42(l-1)+\gamma$, $(\gamma>0, <43)$, and that $l>1$, we have, by equating co-efficients,

$$3.42a=-\frac{1350}{720^2}.3(2_x+2_{x-1})=-\frac{3.1350}{720^2} \qquad \therefore a=-\frac{1350}{42.720^2}.$$

$$-3.42^2a+84b=-\frac{3.5400}{720^2}+\frac{1350}{720^2}\Big\{(2+30+58)2_{x-2} +(16+44+72).2_{x-1}\Big\}$$

$$+\frac{1}{720^2}(7926-8424-1674+1176-1674-8424).(6_{x-1}+6_{x-2} +6_{x-3}+6_{x-4}+6_{x-5}+6_x),$$

$$i.e.\ 84b=-\frac{3.42^2.1350}{42.720^2}+\frac{90.1350}{720^2}+\frac{42.1350}{720^2}.2_{x-1}-\frac{27294}{720^2};$$

$$\therefore b=\frac{-37947+28350.2_{x-1}}{42.720^2}.$$

$$a.42^3-b.42^2+c.42=-\frac{1350}{720^2}\Big((1+15^2+29^2)2_x+(8^2+22^2+36^2)2_{x-1}\Big) +\frac{5400}{720^2}\Big((1+15+29)2_x+(8+22+36)2_{x-1}\Big)$$

$$+\frac{6_{x-1}}{720^2}(-7926+8.8424+15.1674-22.1176+29.1674+36.8424)$$

$$+\frac{6_{x-2}}{720^2}(8424-8.7926+15.8424+22.1674-29.1176+36.1674)$$

$$+\frac{6_{x-3}}{720^2}(1674+8.8424-15.7926+22.8424+29.1674-36.1176)$$

$$+\frac{6_{x-4}}{720^2}(-1176+8.1674+15.8424-22.7926+29.8424+36.1674)$$

$$+\frac{6_{x-5}}{720^2}(1674-8.1176+15.1674+22.8424-29.7926+36.8424)$$

$$+\frac{6_x}{720^2}(8424+8.1674-15.1176+22.1674+29.8424-36.7926).$$

Putting $6_x+6_{x-2}+6_{x-4}$ for 2_x, and $6_{x-1}+6_{x-3}+6_{x-5}$ for 2_{x-1}, and $1=6_x+6_{x-1}+6_{x-2}+6_{x-3}+6_{x-4}+6_{x-5}$, we readily obtain

$$c=\frac{1}{42\cdot 720^2}\Big\{-409860\cdot{}^*6_x+255840\cdot{}^*6_{x-1}-275460\cdot{}^*6_{x-2}$$
$$-12960\cdot{}^*6_{x-3}-141060\cdot{}^*6_{x-4}+121440\cdot{}^*6_{x-5}\Big\}$$

Therefore

$$({}_7P_x)'=\frac{1}{42\cdot 720^2}\Big\{-1350\cdot x^3-(37947-28350\cdot{}^*2_{x-1})x^2$$
$$-{}^*6_x\cdot 409860x+{}^*6_{x-1}\cdot 255840x-{}^*6_{x-2}\cdot 275460x$$
$$-{}^*6_{x-3}\cdot 12960x-{}^*6_{x-4}141060x+{}^*6_{x-5}\cdot 121440x\Big\}+d_x.$$

The value of the constant $d\gamma$ is given by equation (C), thus:

$$({}_7P\gamma)'=[{}_6P_{\gamma-1}]'+[{}_6P_{\gamma-8}]'+\ldots+[{}_6P_{\gamma-36}]', \qquad (C')$$

if $\gamma\overline{\angle}42$; for in that case ${}_7P_{\gamma-42}$ has no terms at all on the right side of equation (A), x being $\overline{\angle}0$. That of d_{42} is obtained immediately by putting $x=0$ in (C) which requires $l=0$, $\gamma=42$; so that (C) becomes, by (c),

$$({}_7P_0)'=0+d_{42}=0, \text{ or}$$
$$d_{42}(=d_{x-427})=d_0=0$$

The remaining 41 values of d_γ, or all the 42 values, are obtained by putting for γ its successive values, 1, 2, 3 ... 42, in the equation (C'), which is, (c) and (P),

$$-d\gamma=\frac{1}{42\cdot 720^2}\Big\{-1350\gamma^3-(37947-28350\cdot 2_{\gamma-1})\gamma^2$$
$$-6_\gamma\cdot 409860\gamma-6_{\gamma-4}\cdot 141060\gamma-6_{\gamma-2}\cdot 275460\gamma$$
$$+6_{\gamma-1}\cdot 255840\gamma+6_{\gamma-5}121440\gamma-6_{\gamma-3}12960\gamma\Big\}$$
$$+\frac{1}{720^2}\Big\{1350\Big(\begin{matrix}(\gamma-1)^2\cdot 2_{\gamma-2}+(\gamma-15)^2\cdot 2_{\gamma-16}+(\gamma-29)^2\cdot 2_{\gamma-30}\\ +(\gamma-8)^2\cdot 2_{\gamma-9}+(\gamma-22)^2\cdot 2_{\gamma-23}+(\gamma-36)^2\cdot 2_{\gamma-37}\end{matrix}\Big)$$
$$+5400\Big(\begin{matrix}(\gamma-1)2_{\gamma-2}+(\gamma-15)2_{\gamma-16}+(\gamma-29)2_{\gamma-30}\\ +(\gamma-8)2_{\gamma-9}+(\gamma-22)2_{\gamma-23}+(\gamma-36)2_{\gamma-37}\end{matrix}\Big)$$

$$+8424\big((\gamma-1)\cdot(6_{\gamma-2}+6_{\gamma-4})+(\gamma-15)(6_{\gamma-16}+6_{\gamma-20})$$
$$+(\gamma-29)(6_{\gamma-30}+6_{\gamma-34})\big)$$
$$-1176\big((\gamma-1)\cdot 6_{\gamma-4}+(\gamma-15)\cdot 6_{\gamma-18}+(\gamma-29)6_{\gamma-32}\big)$$
$$+1674\big((\gamma-8)\cdot(6_{\gamma-10}+6_{\gamma-12})+(\gamma-22)(6_{\gamma-24}+6_{\gamma-26})$$
$$+(\gamma-36)(6_{\gamma-38}+6_{\gamma-40})\big)$$
$$-7926\big(\cdot(\gamma-8)\cdot 6_{\gamma-8}+(\gamma-22).6_{\gamma-22}+(\gamma-36)\,6_{\gamma-36}\big)$$

$$-7926\big((\gamma-1)\cdot 6_{\gamma-1}+(\gamma-15)\cdot 6_{\gamma-15}+(\gamma-29)6_{\gamma-29}\big)$$
$$+1674\big((\gamma-1)(6_{\gamma-3}+6_{\gamma-5})+(\gamma-15)(6_{\gamma-17}+6_{\gamma-19})$$
$$+(\gamma-29)(6_{\gamma-31}+6_{\gamma-33})\big)$$
$$-1176\big((\gamma-8)\cdot 6_{\gamma-11}+(\gamma-22)\cdot 6_{\gamma-25}+(\gamma-36)\cdot 6_{\gamma-29}\big)$$
$$+8424\big((\gamma-8)(6_{\gamma-9}+6_{\gamma-13})+(\gamma-22)(6_{\gamma-23}+6_{\gamma-27})$$
$$+(\gamma-36)(6_{\gamma-37}+6_{\gamma-41})\big)\Big\}.$$

In this expression it is to be borne in mind that $6_{x-7}=0$, whenever $x\angle 7$.

We have now found, in the sum

$$({}_7P_x)+({}_7P_x)',$$

all the terms in x of ${}_7P_x$ which arise from summing all the powers $\gamma 0$ of $x-1$, $x-8$, &c., on the right of equation (A). We have yet to determine $({}_7P_x)''$, the sum of the constants in the same member of (A). Of these there are 60 in every term ${}_6P_{x-1-7a}$, of the form $\frac{1}{720^2}\times f_g.{}^*60_{x-g}$, of which, for a given value of x, only one has value, viz. one of the sixty already given, p. 140.

We know that

$$({}_7P_x)''-({}_7P_{x-420})''=[{}_6P_{x-1}]''+[{}_6P_{x-8}]''+[{}_6P_{x-15}]''+\ldots+[{}_6P_{x-414}]''. \quad (D)$$

If we write $x=420m+60(n-1)+\theta+1$, we have, for $\theta=0$, $x-1=60y+0$, $x-8=60y+53$, $x-15=60y+46$, &c., so that the right member of this equation is $\frac{1}{720^2}\{f_0+f_{53}+f_{46}+f_{39}+$ ... to 60 terms$\}$, that is, it is always the sum of the 60 numbers f_g, the co-efficients of the circulating constant in ${}_6P_x$.

Let now

$$({}_7P_x)''=ax+\beta_x,$$

The equation D is

$$ax-a(x-420)=\frac{1}{720^2}(f_0+f_1+f_2+\ldots+f_{59});$$

for the constant β_x, depending only on the seven values of c and the circulating constant in ${}_6P_x$, can have only 420 values, and $\beta_x=\beta_{x-420}$, which therefore disappears in D. Wherefore

$$420a=-\frac{272430}{720^2},$$

as has been already proved, and

$$a=-\frac{27243}{42.720^2}.$$

The constant β_x is given by putting $x=x'$, $\overline{\equiv}420$; which requires

$$({}_7P_{x'})''=[{}_6P_{x'-1}]''+[{}_6P_{x'-8}]''+\ldots+[{}_6P_{c-1}]'', \text{ i.e.}$$

$$ax'+\beta_x=\frac{1}{720^2}(f_{c-1}+f_{c+6}+\ldots \text{ to } f_{x'-1} \text{ inclusive}),$$

$$\beta_x=\frac{1}{42.720^2}\left\{27243x'+42(f_{c-1}+f_{c+6}+\ldots \text{ to } f_{x'-1})\right\};$$

and $$({}_7P_x)''=\frac{1}{42.720^2}\left\{-27243(x-x')+42(f_{c-1}+f_{c+6}+\ldots \text{ to } f_{x'-1})\right\}.$$

This being added to $({}_7P_x)+({}_7P_x)'$ found before, completes the expression of ${}_7P_x$.

We have then finally, writing

$$x=420m+x'$$
$$=420m+42(n-1)+\gamma$$
$$=420m+42(n-1)+7(i-1)+c;$$

$$(i\overline{\equiv}0, \angle 7), (c\equiv 0, \angle 8), (\gamma\equiv 0, \angle 43), (x'\overline{\equiv}0, \angle 420),$$

$${}_7P_x=\Big[\frac{1}{14\cdot 720^2}\Big\{2(x^6-c^6)+84(+x^5-c^5)+1120(x^4-c^4)+4370(x^3-c^3)$$
$$-9527(x^2-c^2)-55899(x-c)\Big\}$$
$$-\frac{1}{42\cdot 720^2}\Big\{1350(x^3-\gamma^3)+(37947-28350.{}^*2_{x-1})(x^2-\gamma^2)$$
$$+27243(x-x')$$

$$+(x-\gamma)(*6_x\cdot 409860-*6_{x-1}255840+*6_{x-2}275460$$
$$+*6_{x-3}\cdot 12960+*6_{x-4}\cdot 141060-*6_{x-5}\cdot 121440)\Big\}$$
$$+\frac{1}{720^2}\Big\{6(c-1)^5+136(c-1)^4+760(c-1)^3-5046(c-1)$$
$$-1350\big((\gamma-1)^2+(\gamma-15)^2+(\gamma-29)^2\big).*2_x$$
$$-1350\big((\gamma-8)^2+(\gamma-22)^2+(\gamma-36)^2\big)*2_{x-1}$$
$$-5400(\gamma-1+\gamma-15+\gamma-29)*2_x$$
$$-5400(\gamma-8+\gamma-22+\gamma-36)*2_{x-1},$$

(taking and squaring only as many of these six remainders as are positive,)

$$+\{(c-1)+(c+6)+(c+13)+\ldots \text{to } i \text{ terms}\}$$

multiplied singly in order by the c^{th}, $(c+1)^{th}$, $(c+2)^{th}$ . . . of the co-efficients

$$(7926,-8424,-1674,+1176,-1674,-8424)$$

of which the e^{th} is the $(e+6)^{th}$,

$$+(f_{c-1}+f_{c+6}+f_{c+13}+\ldots \text{to } (6(n-1)+i) \text{ terms})\Big\}\Big],$$

where $f_p : 720^2$ is the co-efficient of $P*60_{x-p}$ in ${}_6P_x$, and $f_{p+60}=f_p$.

In the above expression the portion

$$\beta_x=\frac{1}{720^2}\Big\{\frac{272430x'}{420}+\Big(f_{c-1}+f_{c+6}+f_{c+13}+\ldots \text{to } \frac{x'+7-c}{7} \text{terms}\Big)\Big\}$$

may be disregarded. For it is

$$\beta_x=\frac{1}{720^2}\Big\{-\frac{x'}{7}\Big(\frac{f_1+f_2+f_3+\ldots+f_{60}}{60}\Big)+\Big(f_{c-1}+f_{c+6}+\ldots \text{to } \frac{x'+7-c}{7} \text{terms}\Big)\Big\};$$

that is, it is always the sum of h terms f_{c-1}, f_{c+6}, &c., beginning with one of the 7 f_0 f_1 f_2 f_3 f_4 f_5 f_6, diminished by about h times the mean value of the whole 60 numbers f_p. When x' is small, β_x is the sum or difference of two small numbers. When x' is larger, it is seen by inspection of the table of these quantities f_p that no considerable number of them can be taken as $f_{c-1}+f_{c+6}$, &c., that shall not have a negative sum, and shall not with $+\frac{x}{7}\cdot\frac{272430}{60}$ make the numerator of β_x very far less than $259200=\frac{1}{2}720^2$.

This proves that the value of ${}_7P_x$ is always the integer nearest, above or below, to the sum of the terms in x, c, γ; x', and f_{c-1}, &c., being neglected; and I suspect, from the look of the expression, that c and γ may be neglected also.

The terms free from x in ${}_7P_x$ can be reduced to a circulating constant of 420 terms. The shape in which I leave it has at least the advantage of occupying less room, and of showing more of the structure of the function. I am content to lay before the reader a definite expression of these 7-partitions of x, and am convinced that ${}_8P_x$ can be deduced from it with ease by the method here given; and I think this can be done without the labour of writing out at length this tedious constant in ${}_7P_x$.

The portions $({}_8P_x)$ and $({}_8P_x)'$ of ${}_8P_x$ are very easily obtained from the equations

$$({}_8P_x)-({}_8P_{x-8})=[{}_7P_{x-1}],$$
$$({}_8P_x)'-({}_8P_{x-24})'=[{}_7P_{x-1}]'+[{}_7P_{x-9}]'+[{}_7P_{x-16}]',$$

by a process exactly like that employed to find $({}_7P_x)$ and $({}_7P_x)'$. The sum $({}_8P_x)''$ of the circulating constants in ${}_7P_{x-1}+{}_7P_{x-9}+\ldots$ is to be found from

$$({}_8P_x)''-({}_8P_{x-840})''=[{}_7P_{x-1}]''+[{}_7P_{x-9}]''+\ldots+[{}_7P_{x-833}]'',$$

the right side of which is the sum of 105 out of the 420 elements of the constant in ${}_7P_x$. Hence the sum $({}_8P_x)''$ of all these will be of the form

$$S=a^*4_x+b^*4_{x-1}+c^*4_{x-2}+d^*4_{x-3},$$

and can be found easily before the constant in ${}_7P_x$ is fully written out. But I hope that a still more expeditious mode of determining S will be discovered.

In like manner the 9-partitions, 10-partitions, &c. of x may be deduced, each almost by simple transcription from the last preceding, if the constant of this be written out from the formula arising in the process.

X.—*Remarks on the Occultation of Jupiter and his Satellites by the Moon, January 2nd,* 1857.

By the Rev. Henry Halford Jones, F.R.A.S., &c.

[*Read 24th March,* 1857.]

The following observations were made at the Rusholme-road Cemetery, Manchester.

	Greenwich mean time. h.	m.	s.
The fourth Satellite disappeared	4	47	36
The third ditto ditto	4	54	38
First contact of Jupiter with the Moon	5	0	58
Total immersion of Jupiter	5	2	41
The first Satellite disappeared	5	3	21
The second ditto ditto	5	4	27
Last contact of Jupiter with the Moon	5	55	50

The time elapsed between the first contact of Jupiter and his total disappearance was 1 minute and 43 seconds. And the time between the beginning and end of the occultation of the planet, 54 minutes and 52 seconds.

In the earlier part of the evening and during the time in which the several occultations took place, the weather was very fine, and all the objects were beautifully distinct. Not only was the disc of the planet well defined, but his belts and satellites were seen without the slightest difficulty. Not long after the last satellite had disappeared, but more particularly about the time of the planet's reappearance, flying clouds began to interpose, and thus rendered the emersion of the satellites invisible, and the last observed contact of Jupiter with the Moon indistinct and doubtful in time to the extent

of several seconds. In a few minutes afterwards the sky became quite obscure, and a heavy shower of rain began to fall.

The observations were made with a seven-inch Newtonian reflector, and all the phenomena watched with as much vigilance as could be commanded on the occasion, but no perceptible distortion of the planet or the limb of the Moon was observed to take place. Nor did there appear to be any greater difference in the colour of the discs of either Jupiter or the Moon than what might naturally have been expected. During the process of the immersion of the planet, there certainly did seem to be a rather darkly shaded line of demarcation between Jupiter and that part of the Moon's limb projected on the planet's disc. The same phenomenon occurred during the emersion of the planet; but I have a strong impression that this was nothing more than an ocular illusion, occasioned by the juxtaposition and contrast of two objects reflecting differently coloured light, and also differing widely in the intensity of their illumination. Astronomically considered, the whole phenomena were extremely interesting, and, viewed with a contemplative eye, presented a scene of surpassing beauty and sublimity, calculated to awaken in the reflective mind feelings of unusual and intense admiration.

XI.—*Some Peculiarities of the Vital Statistics of the Society of Friends.*

By Alfred Fryer.

[*Read April 7th*, 1857.]

It is now universally acknowledged that the amount of suffering and death caused by the breaking of certain well-known sanitary laws, renders the yearly preventible mortality of our towns greater than that of the most bloody campaign; the number of deaths annually in this country, traceable to causes within our control, is five times as great as the total number of killed, wounded, and missing of the allied army at Waterloo,—thus filth and miasma are more terrible than the sword and the bullet. The mortality of the people in the town is 27 per cent. greater than those in the country districts; anything bearing upon this subject becomes therefore important.

The population of towns, and especially manufacturing towns, comprehends so large a proportion of the poorer classes, that any statistics covering the whole, fail to indicate the amount of mortality due to the vitiated atmosphere and other pernicious effects of densely peopled districts, as they include an excess of deaths due to the occupations, habits, and privations of the poor.

It then becomes an important question: Is there any difference in the average duration of life of two portions of a class of individuals, one living in towns and the other in the country, and both provided with sufficient of the necessaries

of life? If there is any difference, how much? And, if so, at what time of life is the poison of towns most fatal?

Little is known of the average duration of life of the same class of people for successive generations.

To endeavour to throw some light on the above questions is the object of this paper; nevertheless several other subjects are included, some presenting features of novelty, others corroborative of facts already known to the statistician.

In comparing the average duration of life in different times and places, it has appeared difficult to obtain any community whose general circumstances did not allow of changes sufficient to disturb the calculation.

The Society of Friends offers itself as the most promising; their habits have changed less than those of any well-marked class, and they have kept the same relative position in the wealth and industry of the country.

It is pretty well known that the average duration of life in the Society of Friends greatly exceeds that of the people of England generally. The fact has been recorded in the first "report of the commissioners for inquiring into the state of large towns and populous districts;" and is also pointed out in the last edition of Johnstone's Physical Atlas, in the letter-press appended to the map of "health and disease."

This low rate of mortality has been usually attributed to the following circumstances:—

1st. Great attention is paid to cleanliness in their persons and houses.

2nd. They rarely drink to excess or indulge in other intemperance.

3rd. Their children receive careful instruction, and the Society takes charge of the education of the poor among them.

4th. None of their members suffer from the want of suitable food or adequate clothing, as the Society maintains its own poor.

5th. The women are not often employed in other than domestic labour, and mothers can devote time and attention to the bringing up of their children.

Besides these, there are other causes which tend to keep up their average duration of life, viz.:—

1st. There are few early marriages, and the number of births does not more than replace the deaths; thus, as there are fewer children, the number of deaths of children must be relatively smaller than in the country at large.

2nd. The Society of Friends contains an unusually large proportion of females, and as women live longer than men, the average age at death is thus slightly increased.

3rd. The relative number of Friends following unhealthy or laborious occupations is considerably less than in the country at large.

But, on the other hand, Friends are not distributed over the country in the proportion of the population, an undue proportion of them live in large and unhealthy towns, such as Manchester, Liverpool, Leeds, and Bradford, whilst there is a deficiency in the rural districts. On this account, therefore, the average duration of life is less than it would be if Friends were distributed as favourably as the population of the country at large.

The records of births, marriages, and deaths in the Society of Friends have been kept with great accuracy for a long period; and a small publication, "The Annual Monitor," is regularly issued, containing the names, ages, and residences of all the members who die in Great Britain and Ireland each year. The names of children, however, who die under one year are not inserted separately, but a summary of them is appended. This little book is not official; but the information contained is supplied to the editors by all the different registrars. The tables appended to this paper, embracing the years 1842-55 inclusive, are compiled from "The Annual Monitor."

The average age of death is not generally much to be relied on as an indication of the rate of mortality, being so much influenced by the relative number of births and deaths; yet, where these are nearly equal, and there is little fluctuation of numbers from emigration or other causes, the average age at death is trustworthy. The only really correct method of obtaining the rate of mortality is by comparing the annual number of deaths at each age with the number living at the same ages. An enumeration of the Society of Friends in Great Britain and Ireland was made 6th Month 30th, 1847, when there were found to be 18,733 persons living. The average number of deaths per annum for the last fourteen years is 357, therefore 19 per 1,000; or 1 in 51, died annually.

The average deaths per 1,000 living, for the whole country, is 22, or 1 in 45; but were the number of births and deaths equal it would be 1 in 41, or rather more than 24 deaths to 1,000 persons living.

The high rate of mortality in Manchester, Liverpool, and most of the large and densely populated towns, might be regarded as owing chiefly to the overwhelming preponderance of the lower classes. Many of these live in small and ill-ventilated houses, some in closed courts, and others live in cellars; and the greater number are employed at unwholesome or laborious occupations. Their lives are further shortened by addiction to intoxicating drink, by consuming badly-cooked food, by want of cleanliness, and by various privations; the employment of mothers in other than domestic duties, to the neglect of their offspring, tells seriously upon the mortality of children. Taking these things into consideration, it might be supposed that by attention to sanitary laws, the middle classes at any rate might attain as great an age in the town as in the country. To throw some light on this question, nineteen towns, containing a comparatively large number of Friends, have been selected, the age at death of each who died at one year

and upwards during the fourteen years 1842-55 recorded, and the average age at death of these is contrasted with the deaths of Friends in the remainder of Great Britain and Ireland during the same period. The number of children dying under one year has been divided in the proportion of the recorded deaths between one and five years; still the chance of inaccuracy on this ground is small, and cannot seriously affect the results.

Table 1 shows the deaths of males at various ages in the 19 selected towns—London, Bristol, Birmingham, Manchester, Liverpool, Leeds, Preston, Bradford, Newcastle, Sunderland, North and South Shields, Darlington, Hull, Belfast, Clonmel, Cork, Dublin, Limerick, and Waterford — total deaths, 726. Not a single death is recorded at 95 or upwards.

Table 2 shows the deaths of females in the same towns—total 933. Three women died at 95 and upwards.

Table 3 shows the deaths of men in Great Britain, and Table 5 in Ireland, exclusive of the nineteen towns before enumerated; showing, respectively, 1,240 and 62 deaths. Three men died at 95 and upwards.

Tables 4 and 6 show the deaths, as above, of females; being 744 in England, 191 in Ireland. Nine women died at 95 or above. It would thus appear that town life is unfitted for very old persons, and that there are more aged women than men; but as those who attain so great an age as ninety-five are very few, and the Society of Friends is small, not much reliance can be placed upon these deductions.

Tables 8 and 9 are summaries of the deaths of Friends, males and females, in the whole country, and present the following peculiarities. For every 100 boys and 100 girls born there died 14 boys and 8 girls under five years, the deaths of boys thus greatly preponderating. From the ages of 5 to 14 the deaths are nearly equal; from 15 to 24 there is

a greater fatality among men; from 25 to 54 among women; from 55 to 64 among men; from 65 to 74 it is about equal, and from 74 and upwards there being more aged women than men their deaths preponderate.

In tables 10 and 11 we see the contrast between the town and country, which is unfavourable to the former in every particular; and, as tender and young plants are soonest injured by ungenial influences, so we must expect to see the unhealthiness of towns prove especially fatal to children. We accordingly find that up to five years the deaths in towns are double those in the country. It must, however, here be borne in mind that the deaths under one year, though correct for the whole, are divided between the town and country in the proportion of the mortality of the subsequent four years. But, allowing a large margin for the chance of inaccuracy, the fatality of town life to children is excessive. Until the age of 54, when half of the town-born have died (while about two-thirds of the country-born are living), the mortality of the towns is in excess. After that age, as there are a greater number of survivors among the country population the deaths among them are more numerous, so that they appear at first sight to have a lower degree of health, but in the town these same individuals, whose deaths are enumerated, would have already died before that age. An examination of this table is conclusive that something more is wanted for successfully rearing children than suitable food, clothing, and shelter; plenty of pure air cannot with impunity be replaced by a polluted atmosphere, and no amount of nursing and medicine can compensate for the change.

Table 7 is an analysis of the deaths of children under one year, and the preponderance of the deaths of boys over girls is shown throughout. The deaths of boys under one month were 31 in excess of the girls; from one to three months, 8 in excess; from three to six, 14 in excess; six to twelve, 7 in

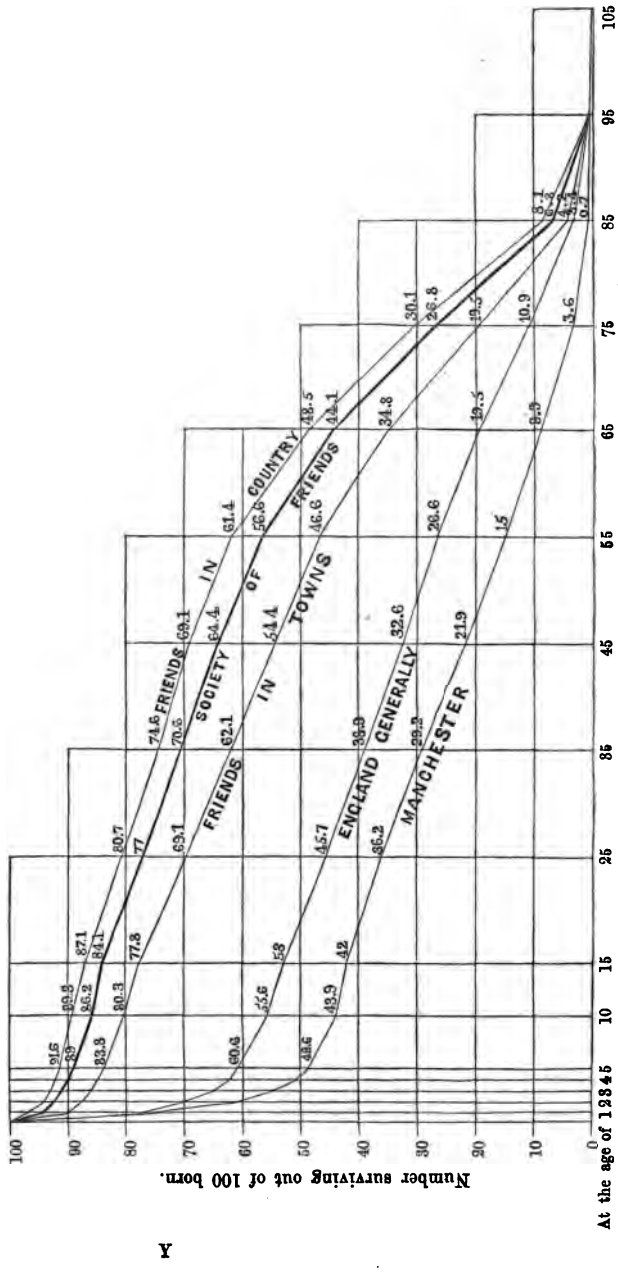
excess. This is the more worthy of notice as the number of females annually dying in the Society is greatly in excess of the males.

Table 13 shows the number of deaths and aggregate of years attained by those dying in the nineteen specified towns and elsewhere, also the average age at death; excluding children under one year. London, Birmingham, Cork, and Darlington appear to be healthy towns; the number dying in some of the other towns is too small to enable us to judge of their respective healthiness except in the aggregate.

Table 14 shows the average length of life in males and females, town and country. It appears that members of the Society of Friends, including both sexes, live on the average to the age of 51 years 1 month, which exceeds by 10 years the average of the people of England generally. The women however live longer than the men—the age of men being 48 years 1 month, and that of women 53 years 4 months. The difference between town and country is remarkably great, and of course in favour of the country. The average length of life in towns is 44 years 8 months, in the country 54 years $3\frac{1}{2}$ months; so that the life of a person in the country is ten years longer or one-fourth more than that of one in a town, that is to say, if 100 persons were born in the town and 100 in the country, for each hour the former live the latter will live an hour and a quarter. When it is considered that the 1,659 persons whose deaths have been recorded in the towns, were as cleanly and temperate, as well fed and as warmly clad as their more fortunately situated friends who lived on the average ten years longer than they, attention is immediately turned to the polluted air of towns, to the effluvia and noxious gases arising from decaying animal and vegetable refuse, sewers, graveyards, and cesspools, to the sulphurous acid, carbonic acid, carbonic oxide, and carbon emanating from the chimneys of our manufactories, and to imperfect ventilation in and around our houses.

It is a serious thing to know that we, in towns, inhale with each breath a poison which is sapping our health and strength, and that though we may exercise the greatest care, we and our families are inevitably defrauded of one-fifth of our lives on the most favourable computation. When we further consider that in the nineteen enumerated towns the average duration of life is raised by several peculiarly healthy towns being included, as well as outskirts of towns, which are generally more healthy; and when we further remember that the list containing the remainder of deaths does not consist entirely of country districts, but includes Friends living in every unhealthy spot in the country, not computed in the nineteen enumerated towns, we cannot but conclude that the difference between town and country life is much greater than here shown. If we contrast the worst towns—Liverpool, with its unenviable notoriety of being the most unhealthy place in the kingdom, with 36 in the 1000 dying annually, Manchester with 33 in the 1000, Leeds 30, Bristol 29, Wigan 28, Bolton and Wolverhampton 27, &c., on the one hand, and the rural districts on the other, we cannot doubt that the difference would be at least 15 to 20 years, however attentive the inhabitants of the former might be with regard to their health.

The mortality of the Society of Friends, as before stated, contrasts very favourably with that of England generally. In the diagram the two are contrasted, the lines relating to the former being constructed on tables 10, 11, and 12, and the latter from the deaths of the people of England registered in the seven years 1838 to 1844, extracted from the Registrar-General's 8th Report. The most marked peculiarity consists in the difference between the deaths of young children, the number dying under one year, being of Friends 6.2, in England generally 22, or $3\frac{1}{2}$ times more than in the Society of Friends. Under five years the deaths of Friends are only one-third of the average of England. The number of deaths


Number surviving out of 100 born.
At the age of 0 5 10 15 25 35 45 55 65 75 85 95 105
100 90 80 70 60 50 40 30 20 10 0
FRIENDS
SOCIETY OF FRIENDS IN COUNTRY
FRIENDS IN TOWNS
ENGLAND GENERALLY
MANCHESTER
91.5 89.8 87.1 84.1 80.7 77 69.1
89 86.2 83.3 80.3 77.3 74.6 70.5
83.3 80.6 75.5 68.6 61.4 56.6 48.5
80.6 75.5 68.6 62.1 56.6 46.6 42.1
60.6 55.5 48.6 43.9 42 34.8 30.1
58 45.7 38.3 32.6 28.6 26.8
43.9 36.2 29.2 21.9 19.5 10.9
42 15 8.9 3.6
8.1 6.3 4.4 3.2 2.7

[*To prevent confusion in the diagram, the figures relating to deaths under one year are inserted separately in the following table.*]

INFANT MORTALITY.

Out of 100 Children born, the Number Surviving at....		*Friends Country.*	*Friends Average.*	*Friends Towns.*	*England Average.*	*Manchester Average.*
	1 year.....	95·6	93.8	90.3	78.0	74.8
	2 ,, ...	94.0	91.8	87.6	70.0	61.0
	3 ,, ...	92.8	90.5	86.1	65.6	55.1
	4 ,, ...	92.1	89.7	84.9	62.7	51.3
	5 ,, ...	91.6	89.0	83.8	60.6	48.6

of Friends at 65 and upwards is 44 out of each 100 born; in England it is only 19½. In England generally, out of a given number born, one-half die before they attain 20 years; in Manchester one-half die before they attain 5 years. In the Society of Friends, 60 years must elapse before one-half die. At extreme old age, 95 and upwards, there would appear to be but little difference between the proportion dying among Friends and others; but as previously stated, the number attaining so great an age is very small, and not sufficient to warrant us in coming to any conclusion. As the Society of Friends does not increase in population the number of births is not in excess of the deaths, and the proportion of children is less than in England generally. This gives a somewhat fictitious increase to the average length of life, and also a corresponding diminution of infant deaths. Nevertheless this effect is small, and need scarcely enter into the calculation.

ANOTHER question naturally arises: Are unhealthy towns deteriorating or improving; have we in Manchester a greater or less expectancy of life than our fathers and grandfathers; is Manchester more or less healthy than it was half a century or a century ago, at least for such portion of the community as live in the most favourable manner, whether the *locality* is healthy or not? A very laborious transcription and classification of the records of the deaths of all persons interred

in the burial grounds of Friends within the limits of the Lancashire Quarterly Meeting, from the commencement of 1777 to the end of 1837, affords some interesting information on this subject. There is no reason to believe that the Society of Friends eighty years ago had fewer personal comforts, were more harrassed by the cares of business, were less cleanly, orderly, or temperate than at the present day, so we must not look to changes in these respects to account for any variation in the duration of life; they probably stood in the same relation to the community as they do now. It should be remarked that the list includes a few persons who died previous to 1777.

Table 15 gives a summary of this investigation. It will be observed throughout that the women live longer than the men, and on the average nearly two years. The proportion of women to men has steadily increased. To each 100 men who died in the twenty years ending 1797, there died 102 women; in the next twenty years 110; in the third twenty years 120. This great increase in the number of women arises from various causes, one of which may be, that more men leave the Society by disownment than women. Still this will only account in part for the remarkable increase of women, and the subject is worthy of investigation.

It must be observed that Table 15, containing the deaths of all persons interred in the burial grounds, includes a number of persons not in membership, but who were connected with Friends and attended their religious meetings; this reduces the average age of death. In Manchester the age at death of Friends only, for the twenty years ending 1856, was 41; for *all* interred in their burial grounds for the same time, 38. Thus we may add three years to each of the ages to form an idea of the age of Friends only.

LANCASTER appears to have been a very healthy town, the average duration of life eighty years ago was greater than that of Manchester at the present time. The duration of

life there has rapidly increased each twenty years. First twenty years, 39; second, 45; third, 49. The women who died in Lancaster during the last twenty years attained the age of 53½, and adding 3 for the correction it would be 56½; but one circumstance, affecting the duration of life of Friends in Lancaster, must be borne in mind, namely, that the number of Friends there has steadily decreased, this will tend to make the average age appear greater.

PRESTON. The number living in this town was so small that no safe comparison can be made of the relative duration of life at different periods; but if we take the total deaths in sixty years, we find the average duration of life 30 years, which must be considered low. More interments of those not members than the average took place in the graveyard of Friends at Preston; this will cause the average duration of life there to appear less.

In LIVERPOOL the records present a very singular appearance; they show for the first twenty years, duration of life 25 years; second, 41; third, 34½. This may, in part, be accounted for on the supposition that the number of Friends decreased after the first twenty years, and after the second twenty increased again. The number of deaths recorded would bear out this supposition, and thus the latter number would a little exceed the correct amount, and the former be a little less. Still this does not fully account for the difference.

It would be hazardous and unsafe on this authority *alone* to assume that the sanitary condition of Liverpool improved up to a certain date; after which, that the extension of docks, the free immigration of the Irish with their habits, the rapid extension of the town without an efficient system of sewers, together with other causes, caused it to deteriorate.

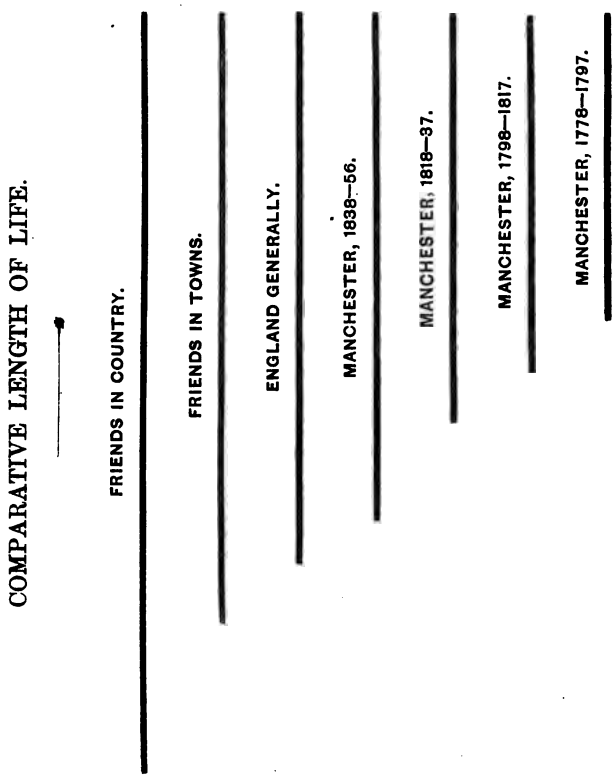
Bad as the statistics of mortality make Manchester appear when compared with other towns, it is cheering to see a progressive and steady increase in the duration of life, not retarded by the increase of the population, nor checked by the yearly increasing smoke and sulphur which we are told are so deadly in their effects. No doubt these are bad enough, but it is pleasant to turn to the brighter side and

to know that we are mending. The result for those interred in the burial grounds of Friends is as follows:—

20 years ending		1797,	average duration of life,	25	years.
„	„	1817,	„	28½	„
„	„	1837,	„	31½	„
„	„	1856,	„	38	„

How marked is the step in the last twenty years, being as much as in the previous forty years! New wide streets, plenty of good water, the removal of old cottage property in the heart of the town, clean streets, good sewers, and extra-mural interments have had their share, no doubt, in raising the average; and are, it is to be expected, destined to improve it still more.

The following lines show at a glance by their length the average duration of life of some of the classes under consideration:—



The deaths in OTHER PARTS of Lancashire, not included in the four towns enumerated, present, at the first sight, a strange appearance. The average age steadily falls—from 43 to 37 and from 37 to 34½—yet this is perfectly consistent, and is one other striking proof of the unhealthy influences in our towns. Eighty to one hundred years ago many of our unhealthy smoky towns were then comparatively healthy hamlets, and at that time nearly all the people who were not included in the largest towns, were living in the country; but now, Wigan, Bolton, Prescot, Warrington, Oldham, and others, have become densely peopled. Thus we cannot assume that the rural district is more unhealthy, but being partly converted into a town district the variation is accounted for.

In the WHOLE OF LANCASHIRE there seems but little change in the duration of life in the last sixty years. The deleterious results arising from the increasing density of the population, and the extension of the cotton manufacture, accompanied with the combustion of so much coal, seem to have been nearly counteracted by the increased knowledge of the laws of health.

A careful examination of the tables will suggest many other points of interest besides those here briefly indicated, but even a cursory glance will show that life may be much prolonged by temperance and care. It will be equally evident that towns are unfavorable to long life, and especially unfitted for young children, whose life is always precarious and who are so easily affected by injurious influences. Still we find that it is quite possible for a town to increase in healthiness whilst it increases in size, so we may hope that by a further knowledge of the laws of health, and more especially by further attention to their requirements, the time will come when the "Health of Towns" may be a reality, not a name.

TABLE No. 1.

SOCIETY OF FRIENDS.

Nineteen Towns in Great Britain and Ireland.—Deaths at different Ages for the Fourteen Years, 1842–55, *inclusive.*

MALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 and upwards.
London	..	..	7	4	..	1	12	6	6	10	4	10	12	23	31	19	7	..
Bristol	..	..	1	..	..	..	1	..	..	5	6	3	3	9	13	8	1	..
Birmingham	..	..	2	..	..	..	2	..	..	3	2	3	1	..	4	5	..	..
Manchester	..	..	..	..	3	..	3	3	1	5	4	5	4	12	6	5	2	..
Liverpool	..	..	1	..	..	1	2	1	2	4	3	6	5	4	8	5	1	..
Leeds	..	..	..	..	1	..	1	3	1	5	4	1	3	7	5	9	2	..
Preston	..	..	..	4	2	..	6	..	2	..	1	1	..	..	1	1	1	..
Bradford	..	..	..	..	..	..	..	1	1	6	1	2	3	3	3	4	..	..
Newcastle	..	..	..	..	..	2	2	1	1	2	3	3	..	1	2	2	..	..
Sunderland	..	..	1	..	..	..	1	2	..	4	..	..	..	4	2	2	..	..
N. and S. Shields.	..	..	1	1	..	..	2	1	1	2	3	..	1	1	2	..	..	..
Darlington	..	..	..	1	..	..	1	2	1	2	1	3	1	6	3	5	2	..
Hull	..	..	..	..	..	..	..	..	1	..	1	..	1	1	2	4	..	..
Belfast	..	..	..	..	..	..	..	1	..	2	3	2	3	1	..	3	1	..
Clonmel	..	..	..	..	2	1	3	3	1	2	1	2	2	2	5	3	..	..
Cork	..	..	1	1	1	..	3	3	2	..	1	3	4	5	7	6	..	..
Dublin	..	..	2	2	1	3	8	2	1	15	8	5	7	7	2	5	2	..
Limerick	..	..	..	2	..	..	2	..	..	3	..	..	5	2	1	..	..	..
Waterford	..	..	1	..	..	..	1	..	2	6	..	2	..	..	3	4	1	..
	726	98	17	15	10	8	148	29	23	76	46	51	55	88	100	90	20	..

TABLE No. 2.

SOCIETY OF FRIENDS.

Nineteen Towns in Great Britain and Ireland.—Deaths at different Ages for the Fourteen Years, 1842-55, *inclusive.*

FEMALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 and upwards.
London	...	...	6	1	2	2	11	4	5	14	13	16	20	26	41	41	14	2
Bristol	...	...	...	1	...	...	1	2	2	5	3	8	7	6	16	23	7	...
Birmingham	...	...	2	...	...	1	3	3	...	3	4	1	7	3	9	9	2	...
Manchester	...	...	3	1	1	2	7	1	1	4	4	3	5	9	7	8	3	...
Liverpool	...	...	5	2	1	2	10	...	2	3	7	2	3	8	17	12	...	...
Leeds	...	...	1	...	...	...	1	2	2	3	3	5	6	3	2	2	1	...
Preston	...	...	1	...	2	1	4	...	...	3	...	...	1	1	3	7	...	...
Bradford	...	...	3	...	...	...	3	1	4	2	2	7	...	4	2	1	...	..
Newcastle	...	..	...	1	1	2	4	2	...	1	2	4	2	5	5	4	3	...
Sunderland	...	...	...	1	...	..	1	2	...	1	4	3	...	1	6	3	1	...
N. and S. Shields	...	...	...	...	1	...	1	1	1	2	1	1	3	2	1	...	1	...
Darlington	...	...	...	...	...	...	...	1	...	2	4	2	...	3	2	8	2	...
Hull	...	...	1	...	...	...	1	...	2	3	3	...	2	3	7	6	...	...
Belfast	...	...	...	1	...	...	1	...	...	5	4	2	1	...	4	3	3	...
Clonmel	...	...	2	...	...	...	2	...	...	3	4	3	3	5	5	4	...	1
Cork	...	...	2	...	...	...	2	3	...	2	4	9	5	8	9	8	...	...
Dublin	...	...	3	1	1	...	5	7	...	9	7	6	6	11	11	16	3	...
Limerick	...	...	...	...	1	...	1	...	...	2	...	...	3	2	...	...	2	...
Waterford	...	...	...	1	...	...	1	1	1	1	2	5	2	7	3	7	4	...
	933	64	29	10	10	10	123	30	20	68	71	77	76	107	150	162	46	3

TABLE No. 3.

SOCIETY OF FRIENDS.

Great Britain, exclusive of Thirteen Towns.—Deaths at different Ages for the Fourteen Years, 1842-55, *inclusive.*

MALES.

	AGES AT DEATH.																	
	Total Deaths.	Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 and upwds	
1842	...	...	5	3	3	...	11	3	1	9	2	3	9	16	18	20	9	...	1842
1843	...	...	2	4	...	...	6	3	1	12	8	3	8	10	16	17	5	...	1843
1844	...	...	2	3	...	2	7	...	1	4	4	11	8	10	15	14	2	...	1844
1845	...	...	4	...	2	...	6	2	1	5	4	4	4	15	24	15	1	1	1845
1846	...	...	2	3	...	...	5	4	...	6	7	3	4	15	20	21	3	...	1846
1847	...	...	2	1	2	...	5	2	...	4	4	3	5	8	28	23	4	...	1847
1848	...	...	2	1	1	...	4	4	3	9	4	2	5	14	11	17	8	...	1848
1849	...	...	2	...	1	...	3	1	1	4	3	4	8	10	17	14	7	...	1849
1850	...	...	1	2	...	2	5	...	...	5	3	4	6	15	15	16	9	...	1850
1851	...	...	1	...	1	...	2	2	3	8	4	3	9	10	14	26	5	...	1851
1852	...	...	2	...	1	1	4	2	2	8	6	3	4	16	16	16	4	...	1852
1853	...	...	3	...	...	1	4	1	2	4	2	4	10	16	19	14	4	1	1853
1854	...	...	1	...	2	1	4	...	2	5	6	4	9	10	20	19	4	...	1854
1855	...	...	2	...	...	...	2	1	4	3	2	6	5	13	14	25	8	...	1855
	1240	73	31	17	13	7	141	25	21	86	59	57	94	178	247	257	73	2	

TABLE No. 4.

SOCIETY OF FRIENDS.

Great Britain, exclusive of Thirteen Towns.—Deaths at different Ages for the Fourteen Years, 1842–1855, *inclusive.*

FEMALES.

	Total Deaths.	AGES AT DEATH.																	
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 and upwds	
1842	...	...	...	1	1	2	4	3	1	2	12	7	12	14	26	26	10	1	1842
1843	...	...	5	2	...	2	9	5	1	9	10	12	9	16	18	31	12	...	1843
1844	...	...	...	1	...	...	1	3	2	10	9	5	10	20	23	26	12	...	1844
1845	...	...	1	1	...	...	2	3	6	6	7	11	14	14	24	27	19	2	1845
1846	...	...	1	1	...	2	4	1	3	7	4	9	5	12	23	26	13	...	1846
1847	...	...	...	1	1	1	3	4	7	4	11	4	6	21	28	36	8	1	1847
1848	...	...	1	4	1	...	6	2	3	10	9	6	11	13	18	35	9	...	1848
1849	...	...	...	1	2	...	3	2	6	8	7	11	9	15	26	26	17	1	1849
1850	...	...	2	...	...	...	2	3	...	1	7	3	7	16	21	25	8	...	1850
1851	...	...	2	...	...	1	3	4	2	4	10	11	8	14	10	28	6	...	1851
1852	...	...	1	1	...	1	3	1	2	14	12	5	10	12	22	28	8	...	1852
1853	...	...	...	...	1	...	1	1	1	6	8	6	9	11	25	34	9	...	1853
1854	...	...	2	1	...	...	3	3	5	5	15	9	11	18	22	34	10	3	1854
1855	...	...	1	3	2	...	6	9	2	5	2	8	14	16	26	32	11	...	1855
	1744	55	16	17	8	9	105	44	41	91	123	107	135	212	312	414	152	8	

TABLE No. 5.

SOCIETY OF FRIENDS.

Ireland: exclusive of Six Towns.—Deaths at different Ages for the Fourteen Years, 1842-55, inclusive.

MALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwds	
1842	..	...	...	1	...	1	2	...	...	1	..	...	...	...	2	1	...	...	1842
1843	...	...	1	2	...	...	3	...	...	4	1	...	1	...	...	3	...	...	1843
1844	...	...	...	...	...	...	...	1	...	3	1	2	...	2	1	2	1	...	1844
1845	...	...	...	...	..	...	...	1	1	2	...	...	1	1	2	2	...	1	1845
1846	...	...	...	...	...	...	...	...	1	...	2	...	1	1	2	...	...	...	1846
1847	...	...	1	...	...	...	1	1	...	1	2	1	...	2	2	5	1	...	1847
1848	...	...	...	...	...	...	...	...	1	2	...	1	1	...	3	3	1	...	1848
1849	..	...	...	...	...	...	...	...	...	...	...	1	2	2	4	2	2	...	1849
1850	...	...	1	...	1	...	2	...	...	1	...	...	2	1	...	3	...	...	1850
1851	...	...	1	...	...	...	1	1	...	1	1	1	...	1	1	...	1	...	1851
1852	...	..	...	...	...	...	...	1	...	...	...	...	...	1	1	1	...	...	1852
1853	...	..	...	...	...	...	...	...	1	...	...	2	...	2	2	3	1	...	1853
1854	...	...	...	...	...	...	...	1	1	...	1	...	1	2	2	4	1	...	1854
1855	...	...	...	1	...	...	1	1	...	2	...	1	...	3	2	2	1	...	1855
	162	14	4	4	1	1	24	7	5	17	8	9	9	18	24	31	9	1	

TABLE No. 6.

SOCIETY OF FRIENDS.

Ireland, exclusive of Six Towns.—Deaths at different Ages for the Fourteen Years, 1842–1855, *inclusive.*

FEMALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwds	
1842	...	...	...	...	...	...	...	1	...	2	1	1	1	...	1	1	4	...	1842
1843	...	...	1	...	...	...	1	...	1	2	1	1	2	3	4	4	1	...	1843
1844	...	...	...	1	...	...	1	...	...	...	3	...	1	2	3	4	...	...	1844
1845	...	...	...	...	...	...	...	...	...	...	1	...	3	3	1	1	4	...	1845
1846	...	...	...	1	...	...	1	...	...	2	...	3	...	5	2	3	3	..	1846
1847	...	...	...	...	...	...	...	...	2	3	1	2	2	...	2	4	3	...	1847
1848	...	...	...	...	1	...	1	...	...	3	1	2	...	...	4	2	2	...	1848
1849	...	...	...	...	...	...	...	...	...	1	...	...	2	1	2	3	2	...	1849
1850	...	...	...	...	1	1	2	1	...	1	2	...	3	1	3	1	2	1	1850
1851	...	...	...	...	...	...	...	...	1	...	1	1	1	1	...	1	...	...	1851
1852	...	...	..	...	...	...	...	...	...	...	...	1	1	2	2	3	...	...	1852
1853	..	...	...	...	...	...	...	...	...	1	1	...	...	...	3	1	1	...	1853
1854	...	...	...	...	...	...	...	...	1	...	2	...	1	2	2	2	1	...	1854
1855	...	...	...	...	...	..	...	...	1	...	1	...	1	2	2	5	...	...	1855
	191	6	1	2	2	1	12	2	6	15	15	11	18	22	31	35	23	1	

TABLE No. 7. SOCIETY OF FRIENDS.

Great Britain and Ireland.—Deaths of Children under 1 *Year, for* 14 *Years,* 1842–1855, *inclusive.*

	Males.					Females.				
	Total Deaths.	Und'r 1 Mo.	From 1 to 3 Mos.	From 3 to 6 Mos.	From 6 to 12 Mos.	Total Deaths.	Und'r 1 Mo.	From 1 to 3 Mos.	From 3 to 6 Mos.	From 6 to 12 Mos.
1842	8	2	..	2	4	8	3	1	1	3
1843	19	7	5	3	4	9	1	4	2	2
1844	12	4	5	..	3	12	2	1	4	5
1845	22	7	2	6	7	4	..	1	1	2
1846	20	6	6	3	5	9	..	3	3	3
1847	11	..	3	3	5	15	1	2	3	9
1848	13	3	1	7	2	10	4	..	..	6
1849	14	2	1	5	6	10	2	2	1	5
1850	5	1	2	1	1	8	1	3	3	1
1851	17	4	4	3	6	11	..	4	4	3
1852	10	5	..	1	4	5	1	..	1	3
1853	13	7	2	3	1	8	4	..	2	2
1854	11	4	2	3	2	9	3	4	..	2
1855	10	2	1	2	5	7	1	1	3	2
	185	54	34	42	55	125	23	26	28	48

TABLE No. 8.

SOCIETY OF FRIENDS.

SUMMARY.—*Deaths at different Ages in Great Britain and Ireland for the Fourteen Years*, 1842-55.

MALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwd.
Nineteen Towns ...	726	98	17	15	10	8	148	29	23	76	46	51	55	88	100	90	20	...
Gt.Britain,excluding thirteen towns ...	1240	73	31	17	13	7	141	25	21	86	59	57	94	178	247	257	73	2
Ireland, excluding six towns	162	14	4	4	1	1	24	7	5	17	8	9	9	18	24	31	9	1
Total	2128	185	52	36	24	16	313	61	49	179	113	117	158	284	371	378	102	3
Per centage	100	8.7	2.5	1.7	1.1	.7	14.7	2.9	2.3	8.5	5.3	5.5	7.5	13.4	17	18	4.8	.1

TABLE No. 9.

FEMALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwd.
Nineteen Towns ...	933	64	29	10	10	10	123	30	20	68	71	77	76	107	150	162	46	3
Gt.Britain,excluding thirteen towns ...	1744	55	16	17	8	9	105	44	41	91	123	107	135	212	312	414	152	8
Ireland, excluding six towns	191	6	1	2	2	1	12	2	6	15	15	11	18	22	31	35	23	1
Total	2868	125	46	29	20	20	240	76	67	174	209	195	229	341	493	611	221	12
Per centage	100	4.4	1.6	1.0	.7	.7	8.4	2.7	2.4	6.0	7.4	6.8	8.0	11.8	17.0	21.4	7.7	.4

TABLE No. 10.

SOCIETY OF FRIENDS.

SUMMARY.—*Deaths at different Ages in* NINETEEN TOWNS *in Great Britain and Ireland for Fourteen Years,* 1842–1855, *inclusive.*

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwd.
Males	726	98	17	15	10	8	148	29	23	76	46	51	55	88	100	90	20	...
Females	933	64	29	10	10	10	123	30	20	68	71	77	76	107	150	162	46	3
Total	1659	162	46	25	20	18	271	59	43	144	117	128	131	195	250	252	66	3
Per centage	100	9.7	2.7	1.5	1.2	1.1	16.2	3.5	2.5	8.7	7.0	7.7	7.8	11.8	15.3	15.3	4.0	0.2

TABLE No. 11.

SUMMARY.—*Deaths at different Ages in* GREAT BRITAIN AND IRELAND, *excluding Nineteen Towns, for the Fourteen Years* 1842–55, *inclusive.*

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwd.
Males	1402	87	35	21	14	8	165	32	26	103	67	66	103	196	271	288	82	3
Females	1935	61	17	19	10	10	117	46	47	106	138	118	153	234	343	449	175	9
Total	3337	148	52	40	24	18	282	78	73	209	205	184	256	430	614	737	257	12
Per centage	100	4.4	1.6	1.2	0.7	0.5	8.4	2.3	2.2	6.4	6.1	5.5	7.7	12.9	18.4	22.0	7.7	0.4

TABLE No. 12.

SOCIETY OF FRIENDS.

SUMMARY.—*Deaths at different Ages in Great Britain and Ireland for the Fourteen Years*, 1842-55.

MALES AND FEMALES.

	Total Deaths.	AGES AT DEATH.																
		Und'r 1 Yr.	1	2	3	4	Und'r 5 Yrs.	5-	10-	15-	25-	35-	45-	55-	65-	75-	85-	95 & upwd.
Great Britain and Ireland	4996	310	98	65	44	36	553	137	116	353	322	312	387	625	864	989	323	15
Per centage	100	6.2	2	1.3	.8	.7	11	2.8	2.1	7.1	6.4	6.2	7.8	12.5	17.3	20	6.5	.3

TABLE No. 13. SOCIETY OF FRIENDS.

Average Age at Death (EXCLUDING CHILDREN WHO HAVE DIED UNDER ONE YEAR), *for the* 14 *Years*, 1842–55 *inclusive.*

PLACES.	Males.			Females.		
	No. of Deaths.	Aggregate Yrs.	Average Age.	No. of Deaths.	Aggregate Yrs.	Average Age.
			Yrs. Mos.			Yrs. Mos.
Gt. Britain & Ireland	1943	102360	52 8	2743	152888	55 9
Gt. Britain, excluding large towns.....	1167	65614	56 3	1690	97270	57 7
Ireland, excluding large towns.....	148	7668	51 10	185	10599	57 4
Total large towns ...	628	29078	46 4	868	45019	51 10
London*	140	7086		207	11539	
Bristol	50	2676		80	4786	
Birmingham	20	964		44	2338	
Manchester	50	2339		52	2508	
Liverpool	41	1971		64	3092	
Leeds.....	41	2101		30	1260	
Preston	13	344		19	940	
Bradford.....	24	1100		26	1090	
Newcastle	16	583		32	1569	
Sunderland.....	15	636		22	1063	
N. & S. Shields ...	13	396		14	538	
Darlington	27	1412		24	1403	
Hull	10	614		27	1421	
Belfast	16	628		23	1119	
Clonmel.....	24	1015		30	1518	
Cork	34	1649		50	2518	
Dublin	62	2260		81	3918	
Limerick	13	490		10	492	
Waterford	19	814		33	1907	

* To prevent conclusions being hastily drawn the average of each town is not given, as great importance can be attached only to the aggregate result.

TABLE No. 14. SOCIETY OF FRIENDS.

SUMMARY.—*Average length of Life, Great Britain and Ireland, for the Fourteen Years* 1842–1855, *inclusive.*

	No. of Deaths.	Years.	Months.
Both Sexes	4996	51	1
Total Males	2128	48	1
„ Females	2868	53	4
Males, 19 Towns	726	40	6
„ remainder Great Britain	1240	52	11
„ remainder Ireland.....	162	47	4
Females, 19 Towns	933	48	3
„ remainder Great Britain ...	1744	55	8
„ remainder Ireland	191	55	6
Total Towns.....	1659	44	8
„ Country	3337	54	3½

TABLE No. 15.

SOCIETY OF FRIENDS.

Interments in the Burial Grounds of Friends within the Quarterly Meeting of Lancashire.

	MALES.		FEMALES.		TOTAL.	
	No. of Deaths.	Av'rage Age.	No. of Deaths.	Av'rage Age.	No. of Deaths.	Av'rage Age.
Lancaster.						
1778 to 1797 inclusive	99	35½	103	42½	202	39
1798 to 1817 „	64	38	73	50½	137	45
1818 to 1837 „	30	41	52	53¼	82	49
Preston.						
1778 to 1797 inclusive	31	19	16	24	47	21
1798 to 1817 „	30	24½	22	37½	52	30
1818 to 1837 „	36	39	41	33	77	35½
Liverpool.						
1778 to 1797 inclusive	106	24½	101	26	207	25
1798 to 1817 „	81	45	95	41½	176	41
1818 to 1837 „	124	35½	138	33	262	34½
Manchester.						
1778 to 1797 inclusive	114	25	111	25	225	25
1798 to 1817 „	129	27½	141	29½	270	28½
1818 to 1837 „	159	27½	182	35	341	31½
1838 to 1856 „	173	36	155	40½	328	38
Remainder of Lancashire Q. M.						
1778 to 1797 inclusive	351	39½	384	47½	735	43
1798 to 1817 „	306	38½	335	35½	641	37
1818 to 1837 „	384	33½	395	35	779	34½
Total of Lancashire Q.M.						
1778 to 1797 inclusive	701	33½	715	39	1416	36½
1798 to 1817 „	610	36	666	36½	1276	36½
1818 to 1837 „	733	33	808	36	1541	34½

XII.—*On the Formation of Indigo-blue.* Part II.

By Edward Schunck, Ph.D., F.R.S.

[*Read April 15th*, 1856.]

In the first part of this memoir I announced the discovery of a peculiar substance contained in the leaves of the *Isatis tinctoria*, to which, as I there showed, the indigo-blue obtained in the usual process of treating the plant owes its origin. Having applied to this substance the name of *Indican*, I proceeded to give a general account of its properties and of the process of decomposition which it undergoes when subjected to the action of strong acids. I now propose to present a more detailed account of the properties of this substance and especially of the products of decomposition derived from it.

In continuing my experiments I soon arrived at the conclusion, that the different methods of preparing indican, of which I had in the first part of this paper given a description, though they sufficed for the preparation of small quantities, were not well adapted for obtaining in a state of purity the larger quantities of the substance which I found to be necessary for the purposes of investigation. The great difficulty in the preparation of indican arises, as I have before stated, from the extreme facility with which it is decomposed, when its solutions, especially the watery one, are heated, a process of decomposition which is rapidly completed at a temperature a little below that of boiling water, and takes place even at the ordinary temperature of the atmosphere, when the evaporation occupies some time. This circumstance

renders its necessary to avoid distilling the solutions or evaporating them at any but the usual temperature. On the other hand, the length of time necessary for the spontaneous evaporation of the watery solution produces in a great measure the same effect as the evaporation of the solution at a higher temperature during a shorter period of time. It therefore became necessary to devise some means of producing a more rapid evaporation of these solutions without the application of artificial heat. This object was attained by means of a simple apparatus, in which a rapid current of air was made to pass over a large surface of the liquid to be evaporated, and which may be described in a few words.

The solution to be evaporated is poured into a dish or tray of block tin about 16 inches square with perpendicular sides 2 inches deep, and capable therefore of containing when full nearly two gallons of liquid. The dish is placed on a shelf fixed at a convenient height in a wooden box of which *a b c d*, Fig. 1, represents the front. This box is closed at the two sides, but open at the front and back from the shelf upwards. It must be sufficiently wide to allow the dish to slide easily in and out, but from front to back it must be so deep as to leave a space of about $\frac{1}{2}$ an inch between the front and the dish. At the distance of about $1\frac{1}{4}$ inch from the back of the box there is fixed in a perpendicular position a board *f*, the upper and side edges of which are firmly attached to the top and sides of the box. The lower edge of this board is about on a level with the upper edge of the tin dish and is accurately fitted to a shelf *g*, which is suspended by means of two upright pieces of wood *h h*, $2\frac{3}{4}$ inches deep, resting on two ledges *i i*, fixed to the sides of the box. The spaces between *h h* and the side walls of the box must be sufficiently wide to allow the sides of the tin dish to move easily up and down in them. By means of supports *n n* inserted between the tin dish *e* and the shelf *o* the former may be raised so as

to bring the surface of the liquid contained in it close to the shelf *g* which is thus made to hang down within the dish. When the apparatus is to be used, the spaces *p p* left between the edges of the dish and the ledges *i i* are closed as tightly as possible by means of flat plugs of wood, so as to cause the current of air passing through the apparatus to sweep over the whole surface of the liquid, and the front of the box is

Fig. 1.

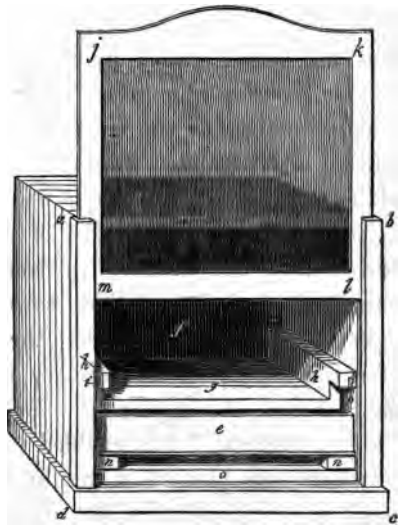
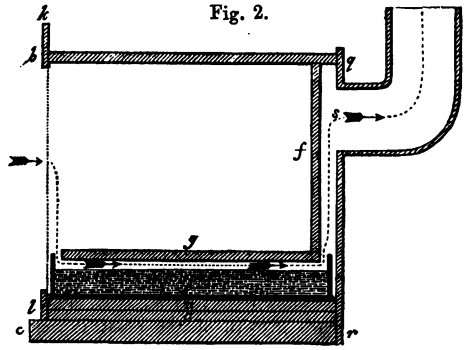


Fig. 2.



closed by means of a frame *j k l m* covered with muslin and sliding up and down in grooves fixed to the sides, which in a

great measure prevents the dust which is carried along by the current of air from being conveyed into the liquid. The apparatus is now placed so as to make the back fit as closely as possible to the wall *q r*, Fig. 2, in which there is an opening *s* communicating with a steam-boiler flue, or the back of the box may be closed with a piece of wood, having an opening communicating by means of a pipe with the flue. The section Fig. 2 shows the direction taken by the air in passing over the surface of the liquid. As the liquid evaporates the dish is raised by means of additional supports, so as again to bring the surface of the former close to the shelf *g* and thus confine the current within a narrow space. The current of air which I employed, and which was sufficiently rapid to cause a constant ripple on the surface of the liquid, was produced by the draught of a steam-boiler flue, which carried away the products of combustion from several large fires. I think it probable, however, that the same effect might be produced by causing the whole of the air necessary for the supply of an ordinary stove or close fireplace to pass through the apparatus. By means of the current of air at my disposal I was enabled to evaporate in this apparatus about one pint of water in the course of twenty-four hours at a temperature not exceeding 10° C., the temperature of the water being kept by means of the rapid evaporation rather lower than that of the atmosphere. The evaporation of a gallon of spirits of wine by the same means occupied only a few hours.

In preparing indican the course of proceeding which I adopt is as follows.* The dried woad leaves are reduced to

* In the course of the investigation I had an opportunity of confirming a statement made by the authors, who have described the cultivation of the woad plant and the preparation of the dye made from it, viz., that the first crop of leaves obtained during the first year's growth of the plant is richest in colouring matter, and that each successive crop yields less than the preceding one. This may perhaps be ascribed to the lower temperature prevailing during the latter part of the year. Nevertheless if the roots be left in the ground through the

a powder, which is passed through a hair sieve, in order to separate the leaf-stalks and ribs of the leaves, and an extract of this powder is then made in a displacement apparatus with cold alcohol in the usual manner. The extract, which may be made stronger by passing it through fresh quantities of powder, has a lively dark green colour. It is evaporated in the apparatus just described, a little water being previously added to it, in order to facilitate the separation of the fatty matter. After a few hours there is found at the bottom of the evaporating dish a dark green layer, consisting of fat and green colouring matter, covered by a light brown watery liquid. The latter is poured off, filtered, agitated with a quantity of freshly precipitated oxide of copper, and filtered again. It now appears of a dark green colour from oxide of copper in solution. The latter having been removed by means of sulphuretted hydrogen, the filtered liquid, which is now quite clear and of a light yellow colour, is evaporated again in the same apparatus, when it leaves a brown syrup. This syrup contains besides indican some products of decomposition of the latter. On being treated with cold alcohol only a portion of it is dissolved, a part remaining undissolved in the form of a brown glutinous substance, which is a product of the combined action of water and oxygen on indican, and which will be

winter, though the plant in the ensuing year seems to have lost none of its vigour, as may be seen by the size and abundance of rich glaucous leaves which it puts forth, and the quantity of flower stems bearing numbers of flowers, and then of seeds which it sends up, still the leaves are as poor in colouring matter as those of the preceding autumn. The inferior quality of the dye produced from the second year's leaves, which in Thuringia went by the name of "Kompts-waid" (see Schreber's Beschreibung des Waids) was well known to the growers of woad in former times.

Woad is still employed by the woollen dyers in this country, but what useful purpose it answers in preference to an equivalent quantity of indigo, I am unable to say. A specimen of the drug, as used by a woollen dyer, which I examined, contained no trace of indigo-blue. If its use be merely to act as a ferment and reducing agent on the indigo employed at the same time, as is very probable, its place might be supplied by rotten cabbage leaves or decaying vegetable matter of any kind.

more fully described below. The alcoholic liquid after being poured off is mixed with about twice its volume of ether, when it becomes milky and deposits a substance of a syrupy consistence, which contains an additional quantity of the body just referred to and also some of the peculiar kind of sugar which is formed by the decomposition of indican. After the mixture has stood for several hours there is usually found deposited on the surface of the syrup and attached to the sides of the glass a quantity of white crystalline needles, which also consist of a product of the decomposition of indican. After the ethereal liquid has become clear, it is poured on a filter and then evaporated as before, when it leaves a clear brown syrup, consisting of indican in as high a state of purity as I have been able to obtain it. The only impurity which may still attach to the indican as thus prepared is a small quantity of fatty matter, the last traces of which it is extremely difficult to remove. When an alcoholic extract of woad is evaporated and water is added to the residue, the filtered liquid, though it may appear tolerably clear, still contains a quantity of fatty matter, in a state either of solution or, as seems more probable, of mechanical suspension. On adding acid to it, this fatty matter separates in greenish masses, which melt when the liquid is heated. The greatest part of this fatty matter is carried down by the oxide of copper used in the process just described, and the remainder is generally removed, when sulphuretted hydrogen is passed through the filtered liquid, by the precipitated sulphuret of copper. A little more separates occasionally in small white grains during the evaporation of the liquid filtered from the sulphuret of copper, especially if the temperature of the current of air passing over its surface be low, as in winter. If, however, the residue left after evaporation of the alcoholic extract be stirred up and agitated for some time with water, so large a quantity of fatty matter becomes suspended in the liquid as to render its separation without de-

composition of the indican almost impossible, and it is for this reason that I have found it advisable always to add water to the alcoholic extract of the leaves before evaporation, and to pour off the watery liquid from the undissolved chlorophyll and fatty matter, instead of evaporating the extract by itself and then stirring up the residue with water.

I have very little to add to the description formerly given of indican and its properties. It is always obtained in the form of a transparent light brown syrup, and it cannot be separated from the water which it still retains in this state without decomposition. Its watery solution has a yellow colour and a purely bitter taste. Even in the highest state of purity in which it can be obtained it produces when dissolved in water a slightly acid reaction on litmus paper. Whether this reaction is peculiar to it, or whether it is a consequence of a commencing decomposition of this easily decomposable substance, I am unable to decide. After being prepared in the manner just described it yields when subjected in small quantities to the action of acids, indigo-blue, indirubine and sugar, with mere traces of other products of decomposition. When the same process however is performed on a somewhat larger scale, other products make their appearance from causes which I shall presently explain.

The new experiments which I have made to determine the composition of indican confirm the conclusions at which I arrived in the first instance and which are contained in the first part of this paper. Being unable to obtain the substance itself in a state fit for analysis, I was obliged, as before, to have recourse to its compound with oxide of lead. This compound was prepared in the following manner. Pure indican was dissolved in cold alcohol, and the solution was mixed with a small quantity of an alcoholic solution of acetate of lead and filtered from the precipitate, which was generally of a somewhat dirty yellow colour. On now adding to the liquid an excess of acetate of lead a bright sulphur-yellow

precipitate fell, which was collected on a filter, washed with alcohol and then dried, at first in vacuo, and then for a few hours in the waterbath. This precipitate was employed in the analyses I. and II. The liquid filtered from this precipitate gave with a little ammonia a second precipitate of a rather paler yellow colour, which was collected on a filter, washed with alcohol and dried in the same manner as the first. The analyses III. and IV. were made with this precipitate. The following results were obtained.

I. 1.0120 grm. burnt with oxide of copper and chlorate of potash gave 0.7590 grm. carbonic acid and 0.1885 water.

1.0330 grm. burnt with soda-lime gave 0.0580 grm. platinum.

0.6385 grm. gave 0.5140 grm. sulphate of lead.

II. 0.8845 grm. gave 0.5040 grm. carbonic acid.

1.1100 grm. burnt with soda-lime gave 0.1260 grm. chloride of platinum and ammonium.

0.3490 grm. gave 0.3260 grm. sulphate of lead.

III. 1.3315 grm. gave 0.9380 grm. carbonic acid and 0.2535 water.

1.6295 grm. gave 0.2145 grm. chloride of platinum and ammonium.

0.8550 grm. gave 0.7005 grm. sulphate of lead.

IV. 0.9520 grm. gave 0.6345 grm. carbonic acid and 0.1715 water.

1.2490 grm. gave 0.0640 grm. platinum.

0.5335 grm. gave 0.4495 grm. sulphate of lead.

These numbers correspond in 100 parts to

	I.	II.	III.	IV.
Carbon.....	20.45	15.54	19.21	18.17
Hydrogen.....	2.06	....	2.11	2.00
Nitrogen.....	0.79	0.71	0.82	0.72
Oxygen.....	17.47	....	17.58	17.12
Oxide of Lead....	59.23	68.73	60.28	61.99
	100.00		100.00	100.00

After deducting the oxide of lead the relative proportions of the other constituents are expressed by the following numbers:

	I.	II.	III.	IV.
Carbon.....	50.15	49.69	48.36	47.80
Hydrogen	5.05	....	5.31	5.26
Nitrogen	1.93	2.27	2.06	1.89
Oxygen.....	42.87	....	44.27	45.05
	100.00		100.00	100.00

These numbers conduct, as will be seen, to two different formulæ. The numbers of the first two determinations lead to the formula $C_{52}\ H_{31}\ NO_{34}$, those of the last two to the formula $C_{52}\ H_{33}\ NO_{36}$ as a comparison of the numbers found by experiment with those required by the respective formulæ will show:

	Eqs.		Calculated.	Eqs.		Calculated.
Carbon....	52	312	49.60	52	312	48.22
Hydrogen..	31	31	4.92	33	33	5.10
Nitrogen ..	1	14	2.22	1	14	2.16
Oxygen ...	34	272	43.26	36	288	44.52
		629	100.00		647	100.00

The first analyses which I made of the lead compounds of indican, and the results of which are recorded in the first part of this paper, led to the formulæ $C_{52}\ H_{35}\ NO_{38}$ and $C_{52}\ H_{37}\ NO_{40}$, but I stated at the same time that neither of these could be considered as the true formula, since the compounds then analysed seemed no longer to contain unchanged indican. However the compounds, the analyses of which have just been given, even after having been completely dried, and decomposed with cold dilute sulphuric acid yielded solutions which, after having been filtered from the sulphate of lead and boiled, deposited flocks consisting almost entirely of indigo-blue and indirubine, products indicating with certainty the presence of unchanged indican. Since indican exhibits a tendency, as I have before observed, to take up successively a number of equivalents of water, it is probable that

of the two formulæ given above, the first, viz., $C_{52}\ H_{31}\ NO_{34}$ approaches nearest to, if it is not a correct representation of its true composition. The formula $C_{52}\ H_{33}\ NO_{36}$ may then represent a mixture of indican with a small quantity of what may be called its hydrate, or it may show the composition of indican in the first stage of its hydration before it has lost the property of yielding indigo-blue by decomposition. As far as regards the explanation of the different processes of decomposition which the substance undergoes, it is of course immaterial which formula is adopted.

Action of Acids on Indican.

In the first part of this memoir I have given a general description of the process of decomposition which indican undergoes by the action of acids and of the products thereby formed. I shall now proceed to give an account of the results obtained in a more minute investigation of this process, performed with larger quantities of material than had previously been at my disposal.

Sulphuric and muriatic acids are not the only acids capable of effecting the decomposition of indican. If to a watery solution of the latter a small quantity of nitric acid be added, the quantity of the acid not being large enough to enable it to exert any oxidising action on the indican, the solution immediately becomes green and turbid, and on standing it deposits flocks of a dark colour, while the surface becomes covered with a blue pellicle. The deposit is found to consist principally of indigo-blue with a little indirubine and a trace of other products of decomposition. The filtered liquid on being boiled becomes muddy and deposits some brown flocks, which contain no indigo-blue. The quantity of indigo-blue formed by the action of nitric acid seems indeed to be comparatively larger than when sulphuric or muriatic acid is employed. It is hardly necessary to add, that if this be really the case, it cannot be ascribed to any oxidising effect produced by the

acid. A watery solution of indican on being mixed with oxalic or tartaric acid and left to stand yields a dark blue or purple deposit, consisting of indigo-blue and indirubine, which when oxalic acid is employed, are remarkably free from other products of decomposition. The liquid filtered from this deposit yields in either case when boiled a few more flocks, and after being filtered, mixed with sulphuric acid and boiled again, it gives an additional quantity. These flocks contain indirubine and indiretine but no indigo-blue. Even acetic acid produces a slight effect on indican. On adding that acid to a watery solution of the latter, the mixture deposits on standing some dark flocks, consisting of indigo-blue and indirubine, but their quantity is trifling.

A more minute examination of this process of decomposition showed that it was more complicated and that the products formed by it were more numerous than I had at first imagined. The products of decomposition which I have observed are of three kinds. The first are insoluble in water and are deposited in the shape of powder or flocks from the acid liquid, the second remain dissolved in the latter, the third are volatile and are obtained by distilling the liquid either whilst the action of the acid is proceeding or after it has ceased. For the purpose of preparing these various products I found it to be unnecessary to obtain indican in a state of absolute purity by successive solution in alcohol, water and ether, for though some indican is always decomposed when its watery solution is evaporated, the substances into which it is thereby converted afford by decomposition with acids, products which do not differ in their nature, but only in their relative proportions from those which are formed, when perfectly pure indican is employed. I therefore contented myself with extracting the dry leaves of the woad plant with cold alcohol, evaporating the extract in the apparatus above described, adding water to the residue and filtering. The solution of indican thus obtained was mixed with a considerable

quantity of sulphuric acid, and the green fatty matter precipitated by the acid was separated by filtration. The action of the acid passed, as I invariably observed, through two distinct stages, and I found it convenient to collect and treat the products formed at each stage of the action separately. The filtered liquid, though clear at first, soon became opalescent and muddy and deposited dark flocks, while the surface became covered with a blue pellicle. After the liquid had stood in the cold for about twenty-four hours, this deposit usually ceased to be formed, and the action then entered on its second stage, which was manifested by the separation from the filtered liquid of a brown powder the quantity of which was much increased by heating. This powder contained little or no indigo-blue, but some indirubine and a large quantity of other products of decomposition. I think it probable that the first deposit owed its origin to the pure indican contained in the solution, while the second was formed from indican that had undergone a change by the action of water. The matter insoluble in water formed by the action of acid having been collected on a filter, the acid liquid was employed for the preparation of the other products of decomposition in a manner to be hereafter described. The portion of the products insoluble in water was also obtained by another method, still more expeditious than the one just described. The leaves of the plant having been finely chopped, boiling water was poured over them, and the mixture having been well stirred the liquid was strained through calico and mixed with sugar of lead. This produced a pale green precipitate which was separated by filtration, and the liquid having been mixed with an excess of sulphuric acid was filtered from the sulphate of lead and heated for some time, when it produced a deposit containing the same products as before. Instead of sulphuric acid I sometimes employed nitric acid, avoiding however in this case the use of heat. More indigo-blue and less of the other pro-

ducts of decomposition seemed to be formed, when nitric acid was used.

In whatever manner the products insoluble in water were obtained, I always adopted the same method of treatment for the purpose of separating them from one another, a method which is indeed essentially the same as that employed by Berzelius for the separation of the constituents of crude indigo. The whole of the acid used in the process having been carefully removed by means of cold water, the mass left on the filter was treated with dilute caustic soda. This dissolved a great portion forming a dark brown opaque liquid, which was filtered from the insoluble matter. The latter was treated again with caustic soda, the action being now assisted by heat, and the process was repeated until nothing more was dissolved. The liquid on being mixed with an excess of muriatic acid let fall a voluminous flocculent precipitate of a brown colour, which after being collected on a filter and washed with water was treated with a boiling mixture of alcohol and ammonia. This sometimes dissolved the whole of it, sometimes only a part. The insoluble portion, when there was any present, had the appearance of a dark brown powder, and consisted of the body to which I have given the name of *Indihumine*. After having been treated repeatedly with alcohol and ammonia, until nothing more was dissolved and then with muriatic acid, and lastly washed with water, it was considered pure. The alcoholic liquid filtered from it was dark brown. On adding to it an excess of acetic acid, an abundant dark brown deposit was formed, consisting of a substance which I had not previously observed, and to which I propose to apply the term *Indifuscine*. It was collected on a filter, washed first with alcohol, then with hot water until all the acetate of ammonia and acetic acid were removed, and lastly agitated with a little cold alcohol, filtered off and dried, when it had the appearance of a dark brown or reddish-brown powder. By repeating the process of solution in alcohol and ammonia and precipitation

with acid, its further purification was effected. The alcoholic liquid filtered from the indifuscine was mixed with an alcoholic solution of acetate of lead, when an additional quantity of the same substance was precipitated in combination with oxide of lead in brown flocks. The filtered liquid, containing an excess of sugar of lead was mixed with ammonia, which gave a brownish-yellow precipitate, consisting chiefly of indiretine in combination with oxide of lead. This precipitate after being filtered off was treated with dilute acetic acid, which removed a considerable quantity of oxide of lead, and after being again filtered off and washed, it was completely decomposed with boiling dilute muriatic acid. The indiretine which was separated collected in the boiling liquid in the form of brown half fused masses, which were separated by filtration while the liquid boiled, washed with boiling water and then treated with a small quantity of cold alcohol. The alcohol acquired a dark brown colour, and after being filtered from a little undissolved indifuscine was evaporated to dryness, when it left the indiretine in the shape of a brittle resinous residue, which was purified by being again dissolved in cold alcohol.

That part of the product of the action of acids insoluble in caustic soda was usually of a dark bluish-purple colour. It was treated with boiling alcohol until nothing more dissolved. The alcoholic liquid, which had a dark brownish-purple colour, was filtered boiling hot from the insoluble portion, consisting chiefly of indigo-blue, and then mixed with ammonia and an alcoholic solution of acetate of lead, which gave a brown precipitate consisting of oxide of lead in combination with indifuscine, and such other products as had not been completely extracted by the caustic soda. After being filtered from this precipitate the liquid appeared of a beautiful purple colour. It was mixed with an excess of acetic acid and distilled or evaporated to about one quarter of its original volume, and then mixed with a large quantity of water, which precipitated the whole of the matter dissolved in it in the shape of dirty

purple flocks. These flocks were collected on a filter, well washed with water and then treated with dilute caustic soda, which generally however only dissolved a minute portion of them. After being again filtered off and well washed they were dried and treated with a small quantity of cold alcohol. The alcohol dissolved a portion forming a solution of a deep reddish-yellow colour, which was filtered and evaporated, when it left a shining resinous substance of the same colour, which as it possesses characteristic properties and a peculiar composition, I shall call *Indifulvine*. By dissolving it in weak spirits of wine it was separated from a little impurity, which remained undissolved in the shape of a brown powder. The matter left undissolved by the cold alcohol consisted chiefly of indirubine. For the purpose of purifying this body I availed myself of the property which it possesses in common with indigo-blue of dissolving in caustic alkalies in the presence of bodies which easily take up oxygen. On treating the mixture containing indirubine with a solution of protoxide of tin in caustic soda and boiling, I obtained a solution, which after being rapidly filtered deposited indirubine on exposure to the air in the shape of a reddish-purple pellicle covering its surface. This pellicle on being broken fell to the bottom in thick flakes and was succeeded by another. As soon as the whole of the indirubine contained in it had been again oxidised and deposited, it was filtered off, well washed with water and dissolved in boiling alcohol. The alcoholic solution which had a beautiful purple colour generally left on evaporation a dark brown amorphous residue consisting of indirubine in as high a state of purity as I have been able to obtain it when formed by the decomposition of indican. A brown powder was left undissolved by the alkaline solution of protoxide of tin, which after being again treated with a fresh quantity of the same solution, in order to dissolve all the indirubine which might be contained in it, was washed with water, then with acid, washed again with

water, dried and treated with cold alcohol. The latter dissolved a second portion of indifulvine, which seemed to have escaped the solvent action of the alcohol in the first instance in consequence of its having been so intimately mixed with and enveloped by particles of indirubine as not to be reached by the alcohol. The alcohol still left undissolved a quantity of brown powder, which did not seem to be any peculiar substance but an intimate mixture of indifulvine and indirubine. The indigo-blue left undissolved by the boiling alcohol was purified by treating it according to Fritzsche's method with a warm solution of grape sugar in alcohol to which caustic soda was added, and allowing the mixture to stand in a warm place until the indigo-blue was dissolved. The yellow solution having been drawn off with a syphon and allowed to stand exposed to the air became first red, then purple, and then deposited the indigo-blue in the shape of small crystalline scales, which were collected on a filter and washed first with alcohol, afterwards with boiling water, then digested with muriatic acid, well washed with water and dried.

The bodies insoluble in water formed by the action of acids on indican are therefore six in number. I shall now give an account of their properties and composition.

Indigo-blue.

The indigo-blue obtained by this process has all the properties usually ascribed to that substance. It is insoluble in alkaline liquids, but dissolves easily when a deoxidising substance, such as a salt of protoxide of tin or protoxide of iron, or grape sugar is added at the same time, the solution exhibiting the usual appearance of an indigo vat, such as the yellow colour, and the blue pellicle on the surface. It is only slightly soluble in boiling alcohol, to which it communicates a blue tinge, but easily and completely soluble in concentrated sulphuric acid, forming a blue solution from which nothing is precipitated on the addition of water. By the action of

boiling nitric acid it yields indigotic acid, and when treated with a strong boiling solution of caustic soda it is converted into an acid, having the properties of anthranilic acid. Its identity with indigo-blue is however placed beyond doubt by its analysis, which yielded the following results:—

I. 0.3365 grm. dried at 100° C. and burnt with oxide of copper and chlorate of potash gave 0.8955 grm. carbonic acid and 0.1305 water.

0.5175 grm. burnt with soda-lime gave 0.3775 grm. platinum.*

II. 0.3605 grm. gave 0.9605 grm. carbonic acid and 0.1350 water.

0.5230 grm. gave 46 CC. of moist nitrogen at a temperature of 12° C. and a pressure of 736.8^{mm} equivalent to 42.7 CC. of dry nitrogen at 0° C. and a pressure of 760^{mm} or 0.0534 grm.

Hence was deduced the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon.....	16	96	73.28	72.57	72.66
Hydrogen...	5	5	3.81	4.30	4.16
Nitrogen....	1	14	10.68	10.36	10.22
Oxygen.....	2	16	12.23	12.77	12.96
		131	100.00	100.00	100.00†

* The double chloride which yielded this amount of platinum was washed according to Hofmann's directions with ether, to which a little alcohol was added instead of with the usual mixture of alcohol and ether. It weighed 0.9095 grm., which if it had consisted of the double chloride of platinum and ammonium alone, would have corresponded to 0.0571 grm. of nitrogen or 11.03 per cent. The apparent excess arose without doubt from the presence of aniline.

† The analyses above given lead to a composition more nearly approaching the theoretical one than any previously on record, with the exception of those given by Laurent (Ann. de Chim. et de Phys. Ser. III., T. 3, p. 372), which were made with sublimed indigo-blue. To the use of the latter for this purpose, however, objections may be raised on account of the difficulty of separating it from particles of carbon and traces of oily and resinous matters formed by the sublimation. Dumas in his last memoir on the composition of indigo-blue (Ann. de. Chim. et de Phys. Ser. III,. T. 2, p. 207) proved that the excess of carbon in the previous analyses of the substance was only apparent, being caused by the admixture of a little sulphur derived from the sulphate of iron which is generally used for its purification. Having carefully removed this

Indirubine.

This substance when obtained by the process above described usually appears in the form of a dark brown amorphous mass. On one occasion, when very pure indican had been employed in its preparation, it was deposited from the boiling alcoholic solution on cooling in long crystalline needles, which were red by transmitted light. The alcoholic solution has a fine purple colour. It is perfectly insoluble in alkaline liquids, but if it be treated with a boiling solution of caustic soda, to which some deoxidising substance, such as protochloride of tin or grape sugar is added, it dissolves with ease, just as indigo-blue does under the same circumstances, forming a solution from which it is again deposited in purple flakes by the action of the atmospheric oxygen. It dissolves in concentrated sulphuric acid in the cold, forming a purple solution, which on the addition of water gives a dark precipitate, the supernatant liquid remaining of a fine purple colour. It is decomposed by boiling nitric acid. On being heated

sulphur, he obtained in three analyses 72.90, 72.84, and 72.97 per cent. of carbon, which correspond apparently with the theoretical composition. These amounts are, however, calculated according to the old atomic weight of carbon. If corrected in accordance with the new atomic weight of carbon, which was established by Dumas a short time previously, they become respectively 71.89, 75.77, and 71.92, the great excess in the second determination being probably due to some misprint. On analysing some specimens of the indigo-blue remaining from his previous investigation, which he himself had proved to be impure, and calculating the results according to the new atomic weight of carbon, Dumas obtained in four analyses 73.3, 73.5, 72.7, and 73.3 per cent. of carbon. The coincidence between these and the previous analyses is of course only apparent. I have myself always found a deficiency in the amount of carbon, unless care was taken to wash the precipitated indigo-blue for a considerable time. I ascribe this circumstance to the indigo-blue like all porous bodies combining with certain substances and removing them from their solutions in consequence of an attraction of surface exerted by it. If, for instance, grape sugar is employed in its purification, a certain quantity of it is carried down by the indigo-blue and can only be removed by continuous washing with hot water, followed by treatment with muriatic acid and renewed washing with water. Each portion of water is found to leave on evaporation a small quantity of syrup, and this does not cease until the washing has been continued for several days.

between two watch-glasses, it produces on the upper glass a sublimate consisting of beautiful purple needles which dissolve in boiling alcohol forming a fine purple solution which on cooling deposits crystalline needles. This sublimate seems to consist, not of any product of decomposition formed by heat, but of the substance itself, which when freed from all impurities possesses the property of crystallising.

The quantity of indirubine which I obtained, even when operating on large quantities of indican, was so exceedingly small, that I was unable to apply any means for effecting its further purification.

I was however enabled by chance to procure from another source a sufficient quantity of the substance for an examination of its properties and composition. Some time before commencing my investigation of the woad plant I had obtained from India a quantity of the dried leaves of the *Indigofera tinctoria* for the purpose of ascertaining the state in which the colouring matter is contained in them. Though the leaves reached me as soon as possible after having been gathered and dried, their examination led to no definite results, the process of fermentation by which the colouring matter is formed having probably been already completed, and I therefore laid them aside. Their peculiar greenish-purple colour and the glaucous appearance of their surface which resembled that of glazed green tea, showed however that they must contain, ready formed, some peculiar species of colouring matter. I was therefore induced to examine them again, and this examination led to the conclusion that their colour was caused by a thin coating of a substance, which was, there could be little doubt, identical with indirubine. This substance was isolated by the following process.

Having prepared a liquid containing protochloride of tin dissolved in an excess of caustic soda, the leaves were immersed in it while boiling. The boiling was continued until the leaves had lost their purple tinge and become pale green.

The green muddy liquid was then strained as quickly as possible through canvas, and left to stand exposed to the air in a shallow vessel. The surface of the liquid soon became covered with a purple pellicle, which was carefully skimmed off and was succeeded by another, which was in its turn removed, the process being repeated as long as anything formed on the surface. The purple matter was then dissolved a second time in an alkaline solution of protoxide of tin and the solution was again left exposed to the atmosphere. The pellicle which was formed by the action of the oxygen was removed this time by means of blotting paper, to which it adhered without much of the liquid underneath being removed with it. The substance was separated from the paper by agitation in water, collected on a filter, treated with boiling caustic soda to dissolve a little adhering fatty matter, filtered off again, washed with acid, then with water, and lastly dissolved in boiling alcohol. The alcohol acquired a splendid purple colour and on cooling deposited a quantity of crystalline needles, consisting, as I believe, of indirubine in a state of purity. When thus prepared it is found to have the following properties.

It crystallises from its alcoholic solution in small needles forming when dry a silky mass of a colour between purple and chocolate, which on being rubbed with a hard body shows a slight metallic lustre, resembling that of bronze. When heated on platinum foil it emits red vapours, then melts and burns with a yellow smoky flame leaving some charcoal. When carefully heated between two watch-glasses it gives a yellowish-red vapour, resembling that of bromine, which condenses on the upper glass in the form of beautiful long crystalline needles. These needles are plum or garnet-coloured, they possess a somewhat metallic lustre, which is however much inferior to that of sublimed indigo-blue, and seem to consist simply of the original substance, which has been volatilised without change. When the process of sub-

limation is carefully conducted only a trace of carbonaceous residue is left. It dissolves completely in concentrated sulphuric acid in the cold, forming a solution of a beautiful purple colour. This solution when heated does not become black, but on the contrary rather paler and evolves only a trace of sulphurous acid. When mixed with water it gives no precipitate and retains its fine purple colour, which does not disappear or become weakened when the acid is neutralised with carbonate of soda, but soon vanishes entirely when an excess of caustic soda or ammonia is added. The solution in sulphuric acid after dilution with water imparts a fine purple colour to cotton, wool, and silk. When treated with nitric acid of ordinary strength indirubine begins to dissolve even in the cold and to a greater extent on the application of heat, forming a purple solution, which on being further heated becomes red and on boiling yellow. The whole of the substance is dissolved without leaving any resinous residue, such is always left when indigo-blue is treated with nitric acid, forming a clear yellow solution. This solution leaves on evaporation a residue which dissolves only partially in hot water. A brown resinous substance is left undissolved by the latter, and the liquid filtered from this is bright yellow and very bitter and yields when mixed with carbonate of potash and evaporated, crystals, apparently of picrate of potash, which detonate when heated. Very dilute nitric acid also decomposes and dissolves it on boiling, but its decomposition is effected with far more difficulty than that of indigo-blue by the same means. In like manner a boiling solution of bichromate of potash, mixed with sulphuric acid, which easily decomposes indigo-blue, seems to have very little effect on it even when the boiling is continued for a considerable time. When suspended in water and exposed to the action of a stream of chlorine gas it loses its colour very slowly and is changed into a brown resinous substance containing chlorine which melts

in boiling water and is easily soluble in alcohol, but does not crystallise when the solution is evaporated. Like the indirubine from indican it is quite insoluble in alkaline liquids, but dissolves easily when a deoxidising agent, such as grape sugar or a protosalt of iron or tin, is added at the same time. If it be treated for instance with a solution of protoxide of tin in an excess of caustic soda it dissolves rapidly, forming a yellow solution, the surface of which on exposure to the air instantly becomes covered with a film of regenerated indirubine, the appearance being exactly like that of an indigo vat, except that the film floating on the surface is purple instead of blue. If a piece of calico be dipped into the solution and then exposed to the air it acquires a purple colour, which is not removed either by acids or soap. This colour has no great intensity, but by working on a larger scale it is probable that shades of purple equal in depth to those produced by indigo-blue might be obtained. When the solution is mixed with an excess of muriatic acid it gives a dirty yellow precipitate, which after filtration and exposure to the air slowly becomes purple. By long continued exposure of the solution to the atmosphere the whole of the indirubine dissolved in it is again deposited as a purple mass, which is sometimes found to consist of small crystalline needles. When heated in a tube with soda-lime the substance emits fumes having a smell like that of benzol and an alkaline reaction, which condense on the colder parts of the tube to a sublimate, consisting partly of oil and partly of crystalline needles. It is not precipitated from its alcoholic solution by acetate of lead, even when ammonia is added at the same time. These reactions seem to me to prove the identity of this body with the indirubine from indican, which if it could be entirely freed from all impurities would no doubt exhibit the same property of crystallising and of volatilising without residue. *

* When dry woad leaves are extracted with cold alcohol, the sides of the glass vessel containing the extract generally become covered with patches of

The behaviour of indirubine towards concentrated sulphuric acid and towards alkaline solutions of deoxidising substances so much resembles that of indigo-blue towards the same reagents as to lead one to expect a great similarity in the composition of the two bodies, even if the fact of their being formed from the same parent substance by the same process of decomposition were unknown. The quantity of pure indirubine, which I obtained from the leaves of the Indigofera, was only sufficient for a general examination of its properties and for one analysis, which showed however, if it be permitted to draw a positive conclusion from one determination, that it has exactly the same elementary composition as indigo-blue, that the two substances are isomeric. The following are the numbers yielded by the analysis:—

0.3185 grm. dried at 100°C. and burnt with oxide of copper and chlorate of potash gave 0.8500 grm. carbonic acid and 0.1195 water.

0.2021 grm. gave 49.3 CC. of nitrogen at a temperature of 10.5° C. and a pressure of $269.5^{mm.}$ equivalent to 16.81 CC. at 0° C. and a pressure of $760^{mm.}$ or 0.2122 grm.*

In 100 parts in contained therefore

Carbon	72.78
Hydrogen	4.16
Nitrogen	10.50
Oxygen	12.56
	100.00

Indifulvine.

This substance is obtained on the evaporation of its alcoholic solution in the form of a deep reddish-yellow, transparent, amorphous resin, which when dry is brittle and may easily be reduced to powder. It is perfectly insoluble in caustic alkalies,

small red crystals, which seem to consist of pure indirubine. They are insoluble in caustic alkalies, but soluble in boiling alcohol, the solution depositing on cooling, crystals exactly like those above described.

* I owe this determination to Professor Frankland, who had the kindness to perform it according to his own method of analysis.

a property by which it may be at once distinguished from indiretine, which it resembles in its outward appearance. Even when grape sugar or protochloride of tin is added to the alkaline liquids not a trace of it dissolves even on boiling, and in this respect it differs widely from indirubine. When it is treated with strong caustic soda lye only a trace of ammonia is given off, but on heating the dry substance with soda-lime there is a very perceptible evolution of ammonia. When heated on platinum it melts and then burns with a bright flame, leaving much charcoal which burns away with difficulty. On being heated in a tube it melts and gives off fumes having a strong smell resembling that of crude indigo when heated. These fumes condense on the colder parts of the tube to a brown oil which on cooling becomes almost solid without exhibiting a trace of anything crystalline. It dissolves in concentrated sulphuric acid in the cold forming a solution of a greenish-brown colour, which when heated becomes black and disengages sulphurous acid. It is not much affected by nitric acid of ordinary strength even on boiling, but fuming nitric acid dissolves it readily, even in the cold, giving a dark reddish-yellow solution, which on the addition of water deposits orange-coloured flocks. If the solution in fuming nitric acid be boiled it gives off nitrous acid, and on evaporation it leaves a reddish-yellow resinous mass, the greatest part of which on being treated with boiling water remains undissolved in the shape of a yellowish-red resin, resembling indifulvine itself in appearance, but differing from it in being easily soluble in alkaline liquids and soluble with difficulty in boiling alcohol. The watery liquid filtered from this resin yields on evaporation white needle-shaped crystals which are not oxalic acid. A boiling solution of bichromate of potash to which sulphuric acid is added decomposes indifulvine very slowly, the solution becoming green from the reduction of the chromic acid. Chlorine converts indifulvine when suspended in water into a body which does

not much differ from it in appearance but is soluble in alkalies. Indifulvine is not precipitated from its alcoholic solution by acetate of lead even on the addition of ammonia, as indeed might be inferred from its method of preparation.

Notwithstanding that I worked with tolerable large quantities of the mixed products of decomposition of indican I obtained only on two occasions, a sufficient quantity of pure indifulvine for analysis. The composition on these two occasions was not the same, so that, if the substance was in each case pure, there are, strictly speaking, two bodies having the general properties of indifulvine. Nevertheless the formulæ of the two bodies stand in a definite relation to one another and to that of indican, so that in either case the formation of the substance may easily be explained.

I. 0.3695 grm. dried at 100° C. gave 0.9945 grm. carbonic acid and 0.1795 water.

0.3605 grm. gave 0.4665 grm. chloride of platinum and ammonium.

These numbers lead to the following composition:—

	Eqs.		Calculated.	Found.
Carbon.....	22	132	73.33	73.40
Hydrogen.....	10	10	5.55	5.39
Nitrogen	1	14	7.77	8.12
Oxygen.....	3	24	13.35	13.09
		180	100.00	100.00

The second analysis afforded the following data:—

II. 0.3125 grm. gave 0.8975 grm. carbonic acid and 0.1635 water.

0.3400 grm. gave 0.4635 grm. chloride of platinum and ammonium.

Hence may be deduced the following composition:—

	Eqs.		Calculated.	Found.
Carbon.....	44	264	78.80	78.32
Hydrogen.....	19	19	5.67	5.81
Nitrogen	2	28	8.35	8.56
Oxygen.....	3	24	7.18	7.31
		335	100.00	100.00

If the first formula be doubled it gives C_{44} H_{20} N_2 O_6, and if from this be deducted 1 equivalent of water and 2 equivalents of oxygen it gives the second formula C_{44} H_{19} N_2 O_3.

For the sake of distinction I think it may be of advantage to apply to the first of these modifications of indifulvine, the term *a* indifulvine and to the second that of *b* indifulvine. The manner in which these bodies are derived from indican can only be understood after all the products of decomposition have been treated of.

Indihumine.

This substance has the appearance of a sepia-brown powder, which is insoluble in water and alcohol, but soluble in alkaline liquids forming brown solutions, from which it is re-precipitated by acids in brown flocks. When heated on platinum it burns without melting leaving some charcoal which easily burns away. Boiling nitric acid decomposes it easily, forming a yellow solution which on evaporation leaves an orange-coloured residue insoluble in water. Indihumine is not always formed in any great quantity in the decomposition of indican by acids. Sometimes indeed it cannot be detected among the products of decomposition, and usually it is present only in minute quantities. What are the circumstances which determine its formation in particular cases I am unable to say. On the only occasion on which I obtained a sufficient quantity for analysis it was procured from an alcoholic extract of woad by evaporating, adding water to the residue and filtering, then adding sulphuric acid to the watery solution containing indican, filtering again, allowing the solution to stand for twenty-four hours, filtering off the indigo-blue and other products which had separated, boiling the liquid, collecting the brown powder which was deposited during the ebullition on a filter, washing it with water and then treating it with a boiling mixture of alcohol and ammonia until nothing more dissolved. The insoluble

residue consisting of indihumine was analysed, when the following numbers were obtained:—

0.3065 grm. dried at 100° C. gave 0.7065 grm. carbonic acid and 0.1300 water.

0.3285 grm. gave 0.3765 grm. chloride of platinum and ammonium.

From these numbers it may be inferred that the composition is as follows:—

	Eqs.		Calculated.	Found.
Carbon.....	20	120	62.82	62.86
Hydrogen.....	9	9	4.71	4.71
Nitrogen	1	14	7.33	7.19
Oxygen.....	6	48	25.14	25.24
		191	100.00	100.00

Indifuscine.

This body so much resembles the preceding in its outward appearance and most of its properties, that the two might easily be confounded. Indifuscine is always obtained in the shape of a dark brown powder, exhibiting sometimes a reddish tinge. It is insoluble in boiling water and only slightly soluble in boiling alcohol, the solution being light brown and depositing a great part of the substance on cooling in brown flocks. It is easily soluble in a mixture of alcohol and ammonia. The solution is dark brown and opaque, and when it is mixed with an excess of muriatic or acetic acid the greatest part of the indifuscine is deposited in the form of a brown powder, while the supernatant liquid retains a brown colour, which is rather darker than that of the solution of the substance itself in boiling alcohol. It is also soluble in watery solutions of caustic and carbonated alkalies, forming brown solutions, from which it is precipitated again by acids in brown flocks. The ammoniacal solution gives brown precipitates with salts of baryta, lime, magnesia, alumina, iron, zinc, copper, lead, mercury, and silver, the whole of the in-

difuscine being precipitated in combination with the respective bases. When indifuscine is heated in a platinum crucible the whole mass begins to heave and is kept in a state of agitation for a few moments, in consequence probably of an evolution of gas at the points of contact with the metal, whereupon it burns but without melting and leaves a considerable quantity of charcoal, which burns away with difficulty without leaving any ash. When heated in a tube it gives fumes having a smell like that of burning turf besides a little oily sublimate, unmixed with anything crystalline. Concentrated sulphuric acid dissolves indifuscine forming a brown solution, which on being heated evolves sulphurous acid. A boiling solution of bichromate of potash to which sulphuric acid is added dissolves and decomposes it rapidly with an evolution of gas, the chromic acid being reduced to oxide of chromium. On being treated with boiling dilute nitric acid indifuscine is decomposed with a disengagement of nitrous acid, giving a yellow liquid which on evaporation yields crystals of oxalic acid. The mother liquor of these crystals on being neutralised with carbonate of potash and evaporated gives brownish-yellow crystals, which detonate when heated and give with acetate of lead, nitrate of silver, and sulphate of iron, reactions showing them to consist of picrate of potash. When finely powdered indifuscine is suspended in water and subjected to the action of chlorine it is converted into a yellow flocculent substance containing chlorine, which is insoluble in boiling water, but dissolves easily in boiling alcohol forming a brown solution, which on spontaneous evaporation leaves a light brown amorphous residue.

When the indican submitted to decomposition with acids has not been purified, the quantity of indifuscine formed far exceeds that of the other products of decomposition, which with the exception of indigo-blue are always produced in comparatively small quantities. In this case a great part of the indifuscine owes its origin to the action of the acid on a body

formed by the influence of water and oxygen on indican. Nevertheless, even when perfectly pure indican is employed, a certain quantity of indifuscine is always produced, especially if the quantity of material used is considerable.

When submitted to analysis indifuscine prepared on different occasions is found to exhibit considerable variation in its composition. The analyses, the results of which I am about to give, were made with specimens, derived from different sources, which notwithstanding the difference in their composition showed no difference in their properties.

I. 0.3135 grm. indifuscine, obtained from the deposit formed on mixing a watery solution of indican with sulphuric acid and allowing the mixture to stand in the cold, dried at 160° C. and burnt with oxide of copper and chlorate of potash, gave 0.6830 grm. carbonic acid and 0.1305 water.

II. 0.3930 grm. obtained by adding sulphuric acid to a watery solution of indican, allowing the mixture to stand for some time in the cold, filtering, and then employing the deposit produced on heating the filtered liquid, gave 0.8720 grm. carbonic acid and 0.1625 water.

0.5675 grm. gave 0.5230 grm. chloride of platinum and ammonium.

III. 0.3435 grm. derived from the deposit formed on mixing a decoction of woad leaves with muriatic acid and boiling, gave 0.7635 grm. carbonic acid and 0.1510 water.

0.4550 grm. gave 0.4365 grm. chloride of platinum and ammonium.

IV. 0.3675 grm. obtained by extracting finely chopped woad leaves with warm water, adding sugar of lead to the extract, filtering from the green precipitate, removing the excess of lead with sulphuric acid, filtering, adding more acid, and treating the flocculent deposit which was formed in the usual manner, gave 0.8950 grm. carbonic acid and 0.1635 water.

0.5715 grm. gave 0.5855 grm. chloride of platinum and ammonium.

V. 0.3640 grm. prepared in a similar manner to the last, gave 0.9020 grm. carbonic acid and 0.1640 water.

0.4470 grm. gave 0.5070 grm. chloride of platinum and ammonium.

These numbers correspond in 100 parts to—

	I.	II.	III.	IV.	V.
Carbon.....	59.41	60.51	60.61	66.41	67.58
Hydrogen...	4.62	4.59	4.88	4.94	5.00
Nitrogen.....		5.78	6.02	6.43	7.12
Oxygen		29.12	28.49	22.22	20.03
		100.00	100.00	100.00	100.00

In passing the eye along these numbers it will be seen that the amount of oxygen decreases progressively from II. to V., while that of the other constituents increases. These two analyses represent in my opinion the composition of the two extreme members of a series, the intermediate members of which consist of mixtures or compounds of the two. A number of other analyses which I made gave results which can only be explained on the supposition that there are two bodies having the same general properties which I have ascribed to indifuscine, but a different composition. Of the above analyses the two first agree tolerably well with the formula $C_{24}\ H_{10}\ NO_9$, whereas the last leads to the formula $C_{22}\ H_{10}\ NO_5$, as the following calculation will show:—

	Eqs.		Calculated.	Eqs.		Calculated.
Carbon....	24	144	60.00	22	132	67.34
Hydrogen..	10	10	4.16	10	10	5.10
Nitrogen ..	1	14	5.83	1	14	7.14
Oxygen ...	9	72	30.01	5	40	20.42
		240	100.00		196	100.00

It will be seen that the two formulæ differ from one another by 2 equivalents of carbonic acid, and hence the name of *Indifuscone* might not be inappropriate for the body whose composition is expressed by the second formula $C_{22}\ H_{10}\ NO_5$.

Though this is the only way in which I am able to explain these discrepancies, still I failed in all my efforts to separate any specimen of the substance having an intermediate composition into two distinct constituents, as every such specimen behaved towards all reagents as if it were one single substance. By treating however a specimen of this kind with a boiling solution of caustic soda for a length of time, the percentage of carbon was increased by about 2.5, showing that the body whose formula is $C_{24}\ H_{10}\ NO_9$ has a tendency to lose carbonic acid and be converted into the one whose composition is expressed by the formula $C_{22}\ H_{10}\ NO_5$. The substance used in this experiment was that employed for the analysis No. III. It was dissolved in caustic soda, the solution was boiled for some time and then mixed with an excess of muriatic acid. The precipitate produced by the acid was dissolved in alcohol and ammonia, and the solution having been mixed with an excess of acid deposited a brown powder, which after being collected on a filter, washed and dried was analysed, when it was found to contain 63.22 per cent. of carbon.

INDIRETINE.

This body, the most striking properties of which have been already mentioned in the first part of this paper, appears on evaporation of its alcoholic solution in the form of a dark brown, shining resin, which is transparent only in very thin layers. It resembles indifulvine in appearance but is distinguished from the latter by its being easily soluble in all alkaline liquids. When heated on platinum foil it melts, swells up very much and burns with a yellow smoky flame, leaving some charcoal which slowly burns away. When heated in a tube it swells up and gives strong smelling fumes together with an oily sublimate, resembling that obtained from indifulvine, which when cool becomes half solid. Con-

centrated sulphuric acid dissolves it in the cold, forming a brown solution, which when boiled becomes black and disengages sulphurous acid. Boiling nitric acid decomposes it with an evolution of nitrous acid, giving a yellow solution, which on evaporation leaves a brown residue consisting of a resinous substance insoluble in water and a little picric acid. When it is treated with boiling caustic soda lye only a trace of ammonia is given off, but when heated with soda-lime there is a much stronger evolution of ammonia. A boiling solution of bichromate of potash to which sulphuric acid has been added slowly decomposes it with an evolution of gas while the liquid becomes green. The solution in ammonia is brown and gives brown precipitates with the chlorides of barium and calcium and with nitrate of silver, while the liquid in each case becomes colourless. The alcoholic solution gives with acetate of lead a brown precipitate, which dissolves entirely on the addition of acetic acid, and with acetate of copper it gives a slight brown precipitate, the filtered liquid being still dark brown.

In the first part of this paper I have given for indiretine the formula $C_{36}\ H_{20}\ NO_{13}$. The analyses, which I have made with fresh preparations of this body, lead to the formula $C_{36}\ H_{17}\ NO_{10}$, as will be seen from the following details.

I. 0.3955 grm. dried at 100° C. and burnt with oxide of copper and chlorate of potash gave 0.9565 grm. carbonic acid and 0.1995 water.

0.5215 grm. burnt with soda-lime gave 0.1400 grm. platinum.

II. 0.4250 grm. of the same preparation heated to 190° C. and then kept for several hours at 100° C. gave 1.0300 grm. carbonic acid and 0.2090 water.

0.5065 grm. gave 0.1370 grm. platinum.

III. 0.4210 grm. of a different preparation gave 1.0200 grm. carbonic acid and 0.2140 water.

The theoretical composition as compared with that derived from these numbers is as follows:—

	Eqs.		Calculated.	I.	II.	III.
Carbon....	36	216	66.05	65.96	66.09	66.07
Hydrogen..	17	17	5.19	5.60	5.46	5.64
Nitrogen ..	1	14	4.28	3.81	3.84	....
Oxygen ...	10	80	24.48	24.63	24.61	....
		327	100.00	100.00	100.00	

I think it is improbable that the discrepancy between the two formulæ, which differ from one another merely by 3 HO, proceeds from any impurity in either case, or that it is to be attributed to the substance having been more carefully dried at one time than at another. Indiretine appears to furnish one of those instances, of which I have met with several during the investigation of this series, of a body exhibiting when prepared on different occasions the same properties but having at one time a composition differing by the elements of water from that which it has at others.

Having described the several products of decomposition formed by the action of acids on indican, which are insoluble in water, I shall now proceed to the consideration of those which are soluble in water. In order to obtain these I found it advisable to employ sulphuric acid for the decomposition of the indican. After the process was completed the insoluble matter deposited was separated by filtration, the sulphuric acid was removed by means of carbonate of lead, and the liquid having been filtered, sulphuretted hydrogen was passed through it in order to precipitate a little lead contained in it, and after being again filtered it was evaporated by means of a current of air in the same apparatus as that employed in the evaporation of solutions of indican. After the evaporation was completed there was left a light brown syrup, which on being treated with alcohol was usually entirely dissolved. The alcoholic solution was filtered if necessary, and then

mixed with about twice its volume of ether, which immediately turned it milky and produced a deposit consisting of a brown syrup. This syrup was allowed to settle and the whole was left to stand for twenty-four hours. The surface of the syrup and the sides of the glass vessel were then found to be covered with a quantity of small, almost white crystals. These crystals are the same as those referred to above as being obtained in the preparation of indican, when ether is added to the alcoholic solution of the latter. I was at first inclined to suppose that they consisted of a substance which was contained as such in the plant, but I soon discovered that they were a product of decomposition of indican, as they were also obtained from perfectly pure indican, which had been prepared by successive solution in alcohol, water and ether, in the last of which the crystals are insoluble. Indeed no product of decomposition of indican seems to be so easily formed as this. By shaking the liquid from which they were deposited the crystals were easily detached from the sides of the vessel and the surface of the syrup. They were collected on a filter, washed with ether, and then pressed between folds of blotting-paper in order to absorb any of the syrup which might be mixed with them. They were then dissolved in boiling water, and the solution having been decolorised with animal charcoal was filtered and evaporated, when it left a crystalline mass, which was again pressed between blotting-paper and dissolved in a small quantity of boiling alcohol. The alcoholic solution on cooling deposited a mass of small crystals, which had the properties and composition of

Leucine.

It crystallised from the alcoholic solution in small flat tables having a pearly lustre, which repelled cold water like a fatty acid but were readily soluble in boiling water. It was insoluble

in ether. When heated in a tube it was completely volatilised without melting, forming a sublimate on the colder parts of the tube in the form of a light mass like cotton. It was easily soluble even in the cold in sulphuric, muriatic and nitric acids. The solution in nitric acid gave off no nitrous fumes on being boiled and left on evaporation a colourless syrup, which on standing was changed into a crystalline mass. The solution in muriatic acid left on evaporation a crystalline residue. It was easily soluble in caustic soda, and the solution evolved no ammonia on being boiled, but when the dry substance was heated with soda-lime it gave off a strong smell of ammonia accompanied by a peculiar penetrating odour. The watery solution was neutral to test paper and had no perceptible taste. When mixed with freshly precipitated oxide of copper and boiled, the watery solution became sky-blue; the filtered liquid gave no precipitate with caustic soda, and on being evaporated left a residue consisting of bright blue crystals. The watery solution gave no precipitate with nitrate of silver, but on the addition of a little ammonia there was deposited almost immediately a quantity of small crystalline scales, which blackened slightly on exposure to the light, and were not easily soluble in an excess of ammonia. The watery solution gave no precipitate with acetate of lead, and even on adding ammonia there was only a slight precipitate, but on allowing the ammoniacal liquid to stand for some hours there was formed a crystalline mass of a pearly lustre consisting of needles arranged in star-shaped masses.

The analysis of the substance gave the following results:—

0.3430 grm. dried at 100° C. and burnt with chromate of lead gave 0.6820 grm. carbonic acid and 0.3125 water.

0.2550 grm. gave 0.4125 grm. chloride of platinum and ammonium.

The composition in 100 parts agrees tolerably well with that required by the formula of leucine $C_{12}H_{13}NO_4$, as will

be seen from the following comparison of the calculated composition with that found by experiment:—

	Eqs.		Calculated.	Found.
Carbon	12	72	54.96	54.22
Hydrogen	13	13	9.92	10.12
Nitrogen	1	14	10.68	10.16
Oxygen	4	32	24.44	25.50
		131	100.00	100.00

However strange the fact of leucine, a substance hitherto supposed to be a product of decomposition peculiar to animal matters, being obtained from the decomposition of a vegetable substance, may have appeared at a former period, it will no longer excite surprise at the present time, when so many different bodies have been found to be common to both classes of organisms. It is a fact however which seems to imply some connection, hitherto unsuspected, between leucine and indigo-blue.

The brown syrup precipitated together with leucine by the addition of ether to the alcoholic solution consisted chiefly of the peculiar kind of sugar produced by the decomposition of indican, and to which as having a composition differing from that of most other species of sugar I propose to give the name of

Indiglucine.

In order to purify it, the brown syrup after the crystals of leucine had been separated by decantation, was dissolved in water and acetate of lead was added to the solution. A slight precipitate was thereby produced, which was separated by filtration, and on adding ammonia to the liquid, a bulky yellowish precipitate fell, consisting chiefly of the lead compound of indiglucine. This was filtered off, completely washed with water and decomposed with sulphuretted hydrogen. The filtered liquid was agitated with animal charcoal until it had

quite lost the yellowish tinge which it showed at first and until a portion of it on being mixed with acetate of lead and ammonia gave a perfectly white precipitate. It was then filtered again and evaporated either in the apparatus above described by means of a current of air or over sulphuric acid. The syrup left after evaporation was dissolved in alcohol and the solution was mixed with twice its volume of ether, when the indiglucine was precipitated as a pale yellow syrup, having a sweetish taste.

To the description formerly given of this substance I have only a few particulars to add. Baryta water gives no precipitate in the watery solution, but on adding alcohol a slight flocculent yellow precipitate is produced. The watery solution after being mixed with milk of lime and filtered is found to have become strongly alkaline and on being boiled becomes quite thick in consequence of the separation of a bulky yellow mass of flocks, which on the liquid cooling is completely redissolved forming a clear yellow solution as before, an experiment which may be repeated any number of times. The solution of the lime compound when mixed with an excess of alcohol gives a bulky yellowish precipitate, after which the liquid appears almost colourless. When treated with boiling nitric acid indiglucine is decomposed and yields oxalic acid. When a watery solution of indiglucine is mixed with yeast and left to stand in a warm place no disengagement of gas is observed nor is any sign of fermentation taking place manifested. After some days however the solution begins to acquire a strongly acid taste and reaction, showing that it has entered into a state of acetous fermentation without having passed through the intermediate stage of the alcoholic fermentation.

The new analyses which I have made of the lead compound confirm the conclusion at which I arrived at an early period of the investigation, viz. that when in combination with oxide

of lead the composition of indiglucine is expressed by the formula C_{12} H_9 O_{11}, and that hence its formula when in an uncombined state is probably C_{12} H_{10} O_{12}.

An analysis of the lead compound, prepared by adding acetate of lead and ammonia to a watery solution of indiglucine, filtering, washing and drying in vacuo, gave the following results:—

0.5640 grm. burnt with chromate of lead gave 0.2430 grm. carbonic acid and 0.0845 water.

0.2495 grm. gave 0.2445 grm. sulphate of lead.

These numbers lead like those of the former analyses to the formula C_{12} H_9 O_{11} + 4 Pb O, as will be seen by comparing the numbers required by theory with those deduced from the analysis.

	Eqs.		Calculated.	Found.
Carbon	12	72	11.69 ·	11.75
Hydrogen	9	9	1.46	1.66
Oxygen	11	88	14.30	14.49
Oxide of Lead	4	446.8	72.55	72.10
		615.8	100.00	100.00

There still remain some products of the action of acids on indican to be treated of. These products are volatile. In order to ascertain their nature I took a solution of indican, mixed it with sulphuric acid and boiled it in a retort, the tube of which passed through a cork into a receiver from which a tube led into a bottle with lime water, the joinings being all air-tight. After the liquid had entered into a state of ebullition and the air had been expelled from the apparatus, bubbles of gas were seen now and then to pass through the lime water, which became milky and deposited a quantity of carbonate of lime. After a great part of the solution had been distilled, the receiver was removed and the liquid contained in it, which was yellowish and had an acid reaction, was mixed

with an excess of carbonate of soda and evaporated to dryness. The saline residue was mixed with an excess of dilute sulphuric acid and the liquid was distilled. The distillate was now colourless. It contained formic acid, for after being neutralised and mixed with nitrate of silver, metallic silver was soon deposited even in the cold. The whole of it was boiled with carbonate of lead, and the filtered liquid was evaporated, when it yielded some shining crystalline needles surrounded by a thick syrup. By means of a little cold water the syrup was removed, the needles being left undissolved. The latter had the properties of formiate of lead.

0.3450 grm. of these needles dried at 100° C. and heated with sulphuric acid gave 0.3505 grm. sulphate of lead, equivalent to 0.2579 oxide of lead or 74.75 per cent. In 100 parts of formiate of lead there are contained by calculation 75.11 parts of oxide of lead.

The liquid poured off from these crystals was mixed with an excess of sulphuric acid, filtered from the sulphate of lead and distilled. The distilled liquid was boiled with peroxide of mercury, in order to decompose any formic acid which it might contain, and filtered, and after sulphuretted hydrogen had been passed through it, it was again filtered from the precipitated sulphuret of mercury. The excess of sulphuretted hydrogen was removed by agitation with carbonate of lead, and the filtered liquid was mixed with an excess of sulphuric acid, filtered again from the sulphate of lead and distilled. The distillation was repeated and the distillate was then boiled with carbonate of silver, filtered and evaporated in vacuo. A residue was left consisting of small white crystalline grains, which repelled water just as if they contained fatty matter. When a portion of this residue was mixed with alcohol and sulphuric acid and the mixture was boiled, a smell like that of butyric ether was given off. The quantity obtained was just sufficient for one analysis, the results of which were as follows:—

0.4420 grm. gave 0.2370 grm. carbonic acid and 0.0925 water.

0.0990 grm. gave 0.0835 grm. chloride of silver.

These numbers correspond in 100 parts to

Carbon	14.62
Hydrogen	2.32
Oxygen	14.87
Oxide of Silver	68.19
	100.00

This composition approximates, as will be seen, to that of acetate of silver, which consists in 100 parts of

Carbon	14.37
Hydrogen	1.79
Oxygen	14.38
Oxide of Silver	69.46
	100.00

The excess in the amount of carbon and hydrogen and the deficiency in that of the oxide of silver show however that it must have contained a small quantity of the silver salt of another acid belonging to the same series as formic and acetic acids, a series having the general formula $C_n H_n O_4$. This acid was probably propionic acid, an acid, the formation of which must indeed be assumed, in order to explain how one of the other products of decomposition of indican takes its rise. The quantity of this acid however contained in the silver salt the analysis of which has just been given was very small, since as may be inferred from the composition of the salt, it was to that of the acetic acid in the proportion of 1 equivalent of the former to 23 equivalents of the latter.

Having described all the products to which the decomposition of indican with acids gives rise, it will now be possible to give an account of the manner in which these various products are formed and of the relation in which they stand to one another.

The decomposition of indican, after taking up several equivalents of water, into 1 equivalent of indigo-blue or indirubine and 3 equivalents of indiglucine will be evident at once from a comparison of the formulæ of these bodies.

The formation of leucine will also be easily understood when it is considered that indigo-blue and 10 equivalents of water, contain the elements of 1 equivalent of leucine, 1 equivalent of formic acid, and 2 equivalents of carbonic acid, as the following equation will show:—

$$\left.\begin{array}{ll} \text{1 eq. Indigo-blue} & C_{16}\,H_5\,NO_2 \\ \text{10 eqs. Water} & H_{10}\,O_{10} \end{array}\right\} = \left\{\begin{array}{ll} C_{12}\,H_{13}\,NO_4 & \text{1 eq. Leucine.} \\ C_2\,H_2\,O_4 & \text{1 eq. Formic acid} \\ C_2\,O_4 & \text{2 eqs. Carb. acid.} \end{array}\right.$$

$$C_{16}\,H_{15}\,NO_{12} \qquad\qquad C_{16}\,H_{15}\,NO_{12}$$

Such a decomposition as this can of course only take place before the elements of indican have arranged themselves in such a manner as to form indigo-blue, which is a body of far too stable a nature to undergo any decomposition by the action of dilute acids.

In order to explain the formation of indifulvine it is necessary to take into consideration the simultaneous formation of formic acid. Indican may be supposed, after taking up 5 equivalents of water, to split up into 1 equivalent of *a* indifulvine, 2 equivalents of indiglucine, and 3 equivalents of formic acid, as will be seen from the following equation:—

$$\left.\begin{array}{ll} \text{1 eq. Indican} & C_{52}\,H_{31}\,NO_{34} \\ \text{5 eqs. Water} & H_5\,O_5 \end{array}\right\} = \left\{\begin{array}{ll} C_{22}\,H_{10}\,NO_3 & \text{1 eq. } a \text{ Indifulvine.} \\ C_{24}\,H_{20}\,O_{24} & \text{2 eqs. Indiglucine.} \\ C_6\,H_6\,O_{12} & \text{3 eqs. Formic acid.} \end{array}\right.$$

$$C_{52}\,H_{36}\,NO_{39} \qquad\qquad C_{52}\,H_{36}\,NO_{39}$$

The following equation shows how the other modification of indifulvine may be supposed to take its rise:—

$$\left.\begin{array}{ll} \text{2 eqs. Indican} & C_{104}\,H_{62}\,N_2\,O_{68} \\ \text{7 eqs. Water} & H_7\,O_7 \end{array}\right\} = \left\{\begin{array}{ll} C_{44}\,H_{19}\,N_2\,O_3 & \text{1 eq. } b \text{ Indifulvine.} \\ C_{48}\,H_{40}\,O_{48} & \text{4 eqs. Indiglucine.} \\ C_{10}\,H_{10}\,O_{20} & \text{5 eqs. Formic acid.} \\ C_2\,O_4 & \text{2 eqs. Carb. acid.} \end{array}\right.$$

$$C_{104}\,H_{69}\,N_2\,O_{75} \qquad\qquad C_{104}\,H_{69}\,N_2\,O_{75}$$

It may further be assumed that 1 equivalent of indican after taking up 4 equivalents of water, is decomposed into 1 equivalent of indihumine, 2 equivalents of indiglucine, 1 equivalent of propionic acid, and 2 equivalents of carbonic acid, as follows:—

$$\left.\begin{array}{l}\text{1 eq. Indican } C_{52}H_{31}NO_{34}\\ \text{4 eqs. Water } \quad H_4 \quad O_4\end{array}\right\} = \begin{cases} C_{20}H_9NO_6 & \text{1 eq. Indihumine.}\\ C_{24}H_{20} \quad O_{24} & \text{2 eqs. Indiglucine.}\\ C_6H_6 \quad O_4 & \text{1 eq. Propionic acid.}\\ C_2 \quad O_4 & \text{2 eqs. Carbonic acid.}\end{cases}$$

$$C_{52}H_{35}NO_{38}$$

The formation of indifuscone is quite analogous to that of indihumine, the propionic acid in the preceding equation being simply replaced by acetic acid, for

$$\left.\begin{array}{l}\text{1 eq. Indican } C_{52}H_{31}NO_{34}\\ \text{3 eqs. Water } \quad H_3 \quad O_3\end{array}\right\} = \begin{cases} C_{22}H_{10}NO_5 & \text{1 eq. Indifuscone.}\\ C_{24}H_{20} \quad O_{24} & \text{2 eqs. Indiglucine.}\\ C_4H_4 \quad O_4 & \text{1 eq. Acetic acid.}\\ C_2 \quad O_4 & \text{2 eqs. Carbonic acid.}\end{cases}$$

$$C_{52}H_{34}NO_{37}$$

The manner in which indifuscine takes its rise from indican needs no explanation, since a comparison of its formula $C_{24}H_{10}NO_9$ with that of indifuscone shows that its composition differs from that of the latter by containing in addition the elements of 2 equivalents of carbonic acid. In its conversion into indiretine, indican splits up into 1 equivalent of the latter body, 1 equivalent of indiglucine, and 4 equivalents of carbonic acid. Here however the anomaly presents itself of a copulated body like indican losing water instead of taking it up during its decomposition into simpler compounds, as will be seen from the following equation:—

$$\text{1 eq. Indican } \quad C_{52}H_{31}NO_{34} = \begin{cases} C_{36}H_{17}NO_{10} & \text{1 eq. Indiretine.}\\ C_{12}H_{10} \quad O_{12} & \text{1 eq. Indiglucine.}\\ C_4 \quad O_8 & \text{4 eqs. Carbonic acid.}\\ H_4 \quad O_4 & \text{4 eqs. Water.}\end{cases}$$

$$C_{52}H_{31}NO_{34}$$

It will be observed that when indican is converted into indigo-blue or indirubine it yields at the same time 3 equivalents of indiglucine, whereas the formation of the other products of decomposition is accompanied by the elimination of no more than 1 or 2 equivalents of that substance. Hence it may be inferred that the appearance of these other products is due to a part of the indiglucine undergoing a further decomposition from the action of the acid, its elements together with the residual portion of the indican affording the materials out of which the other products are formed. In fact we may easily suppose indiglucine, or perhaps more strictly speaking the group of atoms contained in indican which goes to form indiglucine, to split up into 1 equivalent of propionic acid, 1 equivalent of acetic acid, and 2 equivalents of carbonic acid, for

$$C_{12}\,H_{10}\,O_{12} = C_6\,H_6\,O_4 + C_4\,H_4\,O_4 + 2\,C\,O_2$$

Each of these subordinate groups of atoms or any two of them may then be supposed to enter into combination with that portion of the indican which goes to form indigo-blue or indirubine and which may be called its central nucleus. When for instance indihumine is formed, 2 equivalents of indiglucine are produced from the indican, whereas the third equivalent splits up into acetic acid, propionic acid, and carbonic acid. The two latter are set at liberty and may be found among the volatile products of decomposition but the elements of the acetic acid unite with the indigo-blue group of atoms yielding by the combination indihumine. In the case of indifuscone the acetic and carbonic acids derived from the third equivalent of indiglucine are set at liberty, whereas the propionic acid combines with the indigo-blue molecule constituting indifuscone. Indifuscine again may be supposed to consist of indigo-blue, propionic acid and carbonic acid, acetic acid alone being in this case disengaged. In the process of decomposition which leads to the formation of indiretine, only 1 equivalent of indiglucine is eliminated, and 4 equivalents of

carbonic acid are disengaged, while the 2 equivalents of propionic acid as well as the 2 equivalents of acetic acid derived from the other two equivalents of indiglucine unite with the indigo-blue nucleus to produce indiretine. When *a* indifulvine is formed it must be assumed that 1 equivalent of indiglucine after taking up 2 equivalents of water, splits up into 3 equivalents of formic acid and a body represented by the formula $C_6 H_6 O_2$, as follows:—

$$C_{12} H_{10} O_{12} + 2 H O = 3 C_2 H_2 O_4 + C_6 H_6 O_2.$$

Now the last is the formula belonging to the aldehyde of propionic acid and by adding to this formula that of indigo-blue the sum will represent the composition of *a* indifulvine. The more complicated formula given above for *b* indifulvine, viz. $C_{44} H_{19} N_2 O_3$ represents a compound of 2 equivalents of indigo-blue with a body whose formula is $C_{12} H_{12} O_2$ and which is therefore homologous with propylic aldehyde, its origin being due to 2 equivalents of indiglucine being decomposed in such a manner as to give rise to formic acid and carbonic acid in accordance with the following equation:—

$$2 C_{12} H_{10} O_{12} + 2 H O = 5 C_2 H_2 O_4 + 2 C O_2 + C_{12} H_{12} O_2.$$

It will be observed in all these cases, with one exception, viz. that of indihumine, that in the assumed combination of the elements of indigo-blue with those of these various acids &c., one or more equivalents of water must be supposed to be eliminated, as will be seen by a glance at the following equations:—

Indihumine.		Indigo-blue.		Acetic acid.
$C_{20} H_9 NO_6$	=	$C_{16} H_5 NO_2$	+	$C_4 H_4 O_4$

Indifuscone.		Indigo-blue.		Propionic acid.
$H_{22} H_{10} NO_5$	=	$C_{16} H_5 NO_2$	+	$C_6 H_6 O_4 - H O$

Indifuscine.		Indigo-blue.		Propionic acid.
$C_{24} H_{10} NO_9$	=	$C_{16} H_5 NO_2$	+	$C_6 H_6 O_4 + 2 C O_2 - H O$

a Indifulvine.		Indigo-blue.		Propylic aldehyde.
$C_{22} H_{10} NO_3$	=	$C_{16} H_5 NO_2$	+	$C_6 H_6 O_2 - H O$

b Indifulvine. Indigo-blue.

$$C_{44}\,H_{19}\,N_2\,O_3 = 2\,C_{16}\,H_5\,NO_2 + C_{12}\,H_{12}\,O_2 - 3\,H\,O$$

Indiretine. Indigo-blue. Acetic acid. Propionic acid.

$$C_{36}\,H_{17}\,NO_{10} = C_{16}\,H_5\,NO_2 + 2\,C_4\,H_4\,O_4 + 2\,C_6\,H_6\,O_4 - 8\,H\,O$$

It must not for a moment be supposed that these bodies really are compounds of indigo-blue, or that the latter is in any shape contained in them or may be obtained by their decomposition. Indeed all my experiments lead to the conclusion that the elements are arranged in a manner very different from what might be inferred from the above equations. If the nitrogenous substances formed from indican together with indigo-blue were copulated bodies containing the latter, it would be possible to obtain from them either indigo-blue itself or its products of decomposition. With the small quantities of these substances which were at my disposal I was unable to make many experiments to decide this point. A tolerably large quantity of indifuscine was however subjected to the action of a strong caustic soda lye, the liquid being boiled until it left a thick mass which was heated still further, until a small portion of it no longer dissolved in water with a dark brown colour. I was unable however to discover among the products of decomposition a trace of anthranilic acid, which would probably have been present, if indifuscine contained the elements of indigo-blue.

Some advantage may nevertheless arise from looking at these compounds from the point of view just presented, as their relation to one another, to indigo-blue and to indican is thereby more vividly impressed on the memory. This method of considering them may also serve to show that these compounds are all produced at the expense of indigo-blue, that the elements contained in indican which have formed a certain portion of indifulvine, indihumine, &c., might under certain unknown circumstances have produced equivalent quantities of indigo-blue, and that the latter cannot therefore be said in any sense to pre-exist in indican.

Action of Alkalies on Indican.

In the first part of this paper I have described in general terms the effect produced on indican by alkalies. I shall now proceed to give a more detailed account of this process of decomposition and of the products, to which it gives rise.

When a watery solution of indican is mixed with caustic soda it turns of a dark yellow colour, but no further apparent change takes place. If however, after the mixture has been left to stand for several days, a portion of it be mixed with an excess of sulphuric acid and boiled, it deposits dark flocks, which after being collected on a filter and washed are found to contain no indigo-blue and to be entirely soluble in boiling alcohol. The alcoholic solution has a fine purple colour and gives only a slight precipitate with acetate of lead. Hence it follows that by the action of the alkali indican is converted into a body which by decomposition with acids yields indirubine. This body may be prepared in the following manner. A watery solution of indican having been mixed with baryta water is left to stand, until a portion of it on being boiled with an excess of muriatic acid no longer yields indigo-blue but only indirubine. The baryta is then precipitated with sulphuric acid, the excess of the latter is removed by means of carbonate of lead, the liquid is filtered and after sulphuretted hydrogen has been passed through it, it is filtered again from the precipitated sulphuret of lead and then evaporated by means of a current of air in the apparatus above described. The dark yellow syrup left after evaporation is treated with alcohol in which a great part dissolves, and the alcoholic solution is then mixed with twice its volume of ether, which causes a milkiness and produces a syrupy deposit consisting chiefly of indiglucine. The liquid after it has become clear is evaporated spontaneously when it leaves a yellow transparent glutinous residue, having a bitter taste, which cannot be distinguished in outward appearance from indican itself. This residue when dissolved in water and

treated with acid still gives indirubine, in a state of tolerable purity.

On attempting however to prepare this substance on a somewhat larger scale I found it difficult to arrest the process at this stage. As soon as the solution ceased to give indigo-blue with acids, it began to yield with acids a mixture of indirubine and indiretine, and at length it gave indiretine only, after which no further change took place. By allowing a watery solution of indican mixed with baryta water to stand until the decomposition had arrived at its last stage and then treating the solution in the way just described, a substance resembling the preceding was obtained, in the form of a brown syrup, to which I propose to give the name of

Indicanine.

This substance has the following properties. Its taste is bitter like that of indican. When heated on platinum it swells up very much and burns leaving a bulky carbonaceous residue. When heated in a tube it gives fumes, condensing to a brown liquid, which after some time becomes filled with a quantity of white crystalline needles. It is perfectly soluble in alcohol and ether. The alcoholic solution gives with an alcoholic solution of acetate of lead a bright sulphur-yellow precipitate which dissolves when more acetate of lead is added and the liquid is boiled, forming a yellow solution, in which ammonia again produces a yellow precipitate like the first. The watery solution gives only a slight precipitate with acetate of lead, but the filtered liquid yields a copious yellow precipitate on the addition of ammonia. When the watery solution is mixed with sulphuric acid and boiled it slowly deposits a quantity of brown resinous particles, which are entirely soluble in caustic soda and consist of indiretine and a little indifuscine. On adding caustic soda to a watery solution of indicanine it becomes dark yellow and on being boiled disengages ammonia,

but exhibits no further change. The analysis of the lead compound, prepared by adding acetate of lead to the alcoholic solution, filtering and washing with alcohol, yielded the following results:—

0.7840 grm. dried first in vacuo and then at 100° C. burnt with oxide of copper and chlorate of potash gave 0.6115 grm. carbonic acid and 0.1480 water.

1.0350 grm. gave 0.2225 grm. chloride of platinum and ammonium.

0.3785 grm. gave 0.3010 grm. sulphate of lead.

Hence was deduced the following composition:—

	Eqs.		Calculated.	Found.
Carbon	40	240	21.06	21.27
Hydrogen	23	23	2.01	2.09
Nitrogen	1	14	1.22	1.35
Oxygen	24	192	16.88	16.78
Oxide of Lead.	6	670.2	58.83	58.51
		1139.2	100.00	100.00

After deducting the oxide of lead the amount of the other constituents in 100 parts as compared with the calculated composition is as follows:—

	Eqs.		Calculated.	Found.
Carbon.....	40	240	51.17	51.26
Hydrogen	23	23	4.90	5.03
Nitrogen	1	14	2.98	3.25
Oxygen	24	192	40.95	40.46
		469	100.00	100.00

In the first part of this paper I gave an analysis of the lead compound of a substance having the formula $C_{40}\ H_{36}\ NO_{27}$ which differed therefore in composition from this merely by containing the elements of 3 equivalents more of water. As it was impossible to analyse these substances in an uncombined state, there were no means of ascertaining whether in that state they had the same composition, as was most probably the case.

Indicanine is formed from indican simply by the latter taking up water and losing 1 equivalent of indiglucine, as will be seen from the following equation:—

$$\left.\begin{array}{ll} 1 \text{ eq. Indican} & C_{52}\,H_{31}\,NO_{34} \\ 2 \text{ eqs. Water} & H_2\quad O_2 \end{array}\right\} = \left\{\begin{array}{ll} C_{40}\,H_{23}\,NO_{24} & 1 \text{ eq. Indicanine.} \\ C_{12}\,H_{10}\quad O_{12} & 1 \text{ eq. Indiglucine.} \end{array}\right.$$

$$C_{52}\,H_{33}\,NO_{36} \qquad C_{52}\,H_{33}\,NO_{36}$$

The indiglucine formed in the process is contained in the brown syrupy deposit which falls on adding ether to the alcoholic solution of the indicanine. Some of this deposit, after the liquid had been poured off, was dissolved again in alcohol, the solution was mixed with an excess of alcoholic solution of acetate of lead, which produced a brown glutinous precipitate, and to the filtered liquid was added an excess of ammonia, which gave a bulky sulphur-yellow precipitate. This precipitate was collected on a filter, washed with water and decomposed with sulphuretted hydrogen, and the filtered liquid was agitated with animal charcoal until it had lost the yellowish tint which it possessed at first. The liquid having been again filtered was mixed with acetate of lead and ammonia, which produced a milk-white precipitate. This precipitate after being filtered off was redissolved in a mixture of alcohol and acetic acid, and by the addition of a small quantity of ammonia a white precipitate was again produced, which was filtered off and washed with alcohol.

1.0230 grm. of this precipitate dried in vacuo gave 0.4780 grm. carbonic acid and 0.1510 water.

0.6095 grm. gave 0.5780 grm. sulphate of lead.

In 100 parts it contained therefore

Carbon	12.74
Hydrogen	1.64
Oxygen	15.85
Oxide of Lead	69.77
	100.00

If the oxide of lead, the amount of which stands in no

simple relation to that of the other constituents, be deducted, the composition of the body combined with it will be represented by the formula C_{12} H_9 O_{11}, which is that of anhydrous indiglucine, as will be seen from the following calculation:—

	Eqs.		Calculated.	Found.
Carbon.....	12	72	42.60	42.14
Hydrogen.....	9	9	5.32	5.42
Oxygen.....	11	88	52.08	52.44
		169	100.00	100.00

The manner in which indiretine and indifuscine are formed from indicanine needs no explanation, since the composition of the latter differs from that of indican merely by the elements of 1 equivalent of indiglucine. It is however difficult to explain why indicanine by decomposition with acids should yield only these products and no indigo-blue, indirubine, or indifulvine, which might, as far as their composition is concerned, be produced at the same time, and I am quite unable to assign any cause for this phenomenon. It seems to me very probable that the indiretine and indifuscine which are formed when pure indican in large quantities is decomposed with acids owe their origin to the conversion of a portion of the indican into indicanine, before the acid has had time to effect the more complete decomposition of this portion into indigo-blue or indirubine and indiglucine.

Indican is decomposed when its watery solution is heated for a length of time, in exactly the same manner as by means of alkalies. After the solution has been heated for some time it no longer gives any indigo-blue when a portion of it is boiled with sulphuric acid. If it be now evaporated in the same apparatus as that used for evaporation of solutions of indican it leaves a brown syrup, a great part of which dissolves in alcohol. On adding ether to the alcoholic solution a syrupy deposit of indiglucine is produced followed by the separation of crystals of leucine. If the liquid be filtered and evaporated it leaves a brown glutinous residue having

the properties of indicanine. The lead compound which was obtained in the form of a sulphur-yellow precipitate by adding acetate of lead to the alcoholic solution, was after being filtered off and washed with alcohol submitted to analysis when it gave the following results:—

1.2580 grm. dried first in vacuo and then in the waterbath, gave 0.8320 grm. carbonic acid and 0.2040 water.

1.5655 grm. gave 0.2740 grm. chloride of platinum and ammonium.

0.7620 grm. gave 0.6610 grm. sulphate of lead.

These numbers correspond in 100 parts to

Carbon	18.03
Hydrogen	1.80
Nitrogen	1.09
Oxygen	15.26
Oxide of Lead	63.82
	100.00

The oxide of lead being deducted, the substance combined with it was found to have a composition agreeing with the formula $C_{40}\ H_{24}\ NO_{25}$, as will be seen by a comparison of the calculated composition with that found by experiment:—

	Eqs.		Calculated.	Found.
Carbon	40	240	50.20	49.85
Hydrogen	24	24	5.02	4.98
Nitrogen	1	14	2.92	3.01
Oxygen	25	200	41.86	42.16
		478	100.00	100.00

When a watery solution of indican or indicanine is evaporated in contact with the air, either spontaneously or with the assistance of heat a portion of it is always converted into a substance which is insoluble not only in ether but also in alcohol. That the formation of this substance is due to the action of oxygen on indicanine is proved by analysis. Its formation moreover is promoted by heating the solution of indicanine with peroxide of lead, the filtered liquid after

the dissolved lead has been removed with sulphuretted hydrogen leaving on evaporation a residue which is insoluble in alcohol. It differs however in composition according as the solution of indican has been evaporated spontaneously or with the assistance of heat. The body which is formed when a watery solution of indican is spontaneously evaporated in contact with the air, I propose to call

Oxindicanine.

So much of this body is produced during the preparation of indican, that I found it unnecessary to prepare it purposely. When the residue left after the evaporation of the watery solution of indican by means of a current of air, as described above, is treated with cold alcohol, the greatest part of the oxindicanine formed during the process remains undissolved. It may be purified simply by dissolving it in a little water and precipitating again with a large quantity of alcohol. Its appearance is that of a brown glutinous substance, which on being left to stand over sulphuric acid becomes almost dry and assumes the appearance of gum. It is insoluble in absolute alcohol and only slightly soluble in dilute alcohol. When heated on platinum it swells up very much and burns leaving a considerable carbonaceous residue. It yields when heated in a tube strong smelling fumes but only a slight trace of crystalline sublimate. Its taste is nauseous but not bitter. Its watery solution gives with acetate of lead a copious dirty yellow precipitate, and the filtered liquid gives a pale primrose-yellow precipitate on the addition of ammonia or of a large excess of alcohol. When the watery solution is mixed with sulphuric acid and boiled it slowly deposits brown flocks, which have the properties of indifuscine, while the liquid contains indiglucine. For the purpose of determining its composition I employed the lead compound, prepared by adding acetate of lead to the watery solution, filtering and washing with water.

I. 0.8515 grm. of this precipitate dried first in vacuo and then at 100° C. gave 0.7310 grm. carbonic acid and 0.1735 water.

1.1640 grm. gave 0.2575 grm. chloride of platinum and ammonium.

0.5185 grm. gave 0.3460 grm. sulphate of lead.

II. 1.2640 grm. of another preparation gave 1.0495 grm. carbonic acid and 0.2430 water.

1.5500 grm. gave 0.2505 grm. chloride of platinum and ammonium.

0.7730 grm. gave 0.5250 grm. sulphate of lead.

Hence the composition in 100 parts was as follows:—

	I.	II.
Carbon	23.41	22.64
Hydrogen	2.26	2.13
Nitrogen	1.38	1.01
Oxygen	23.85	24.25
Oxide of Lead	49.10	49.97
	100.00	100.00

After deducting the oxide of lead the first analysis gives a composition agreeing with the formula $C_{40}\,H_{22}\,NO_{31}$, whereas the second leads to the formula $C_{40}\,H_{23}\,NO_{32}$, as is shown by a comparison of the calculated numbers with those deduced from the above analyses.

	Eqs.		Calculated.	I.	Eqs.		Calculated.	II.
Carbon	40	240	45.80	45.99	40	240	45.02	45.25
Hydrogen	22	22	4.19	4.44	23	23	4.31	4.25
Nitrogen	1	14	2.67	2.71	1	14	2.62	2.01
Oxygen	31	248	47.34	46.86	32	256	48.05	48.49
		524	100.00	100.00		533	100.00	100.00

If the second formula be adopted as the correct one it follows that indicanine is simply converted into oxindicanine by taking up 8 equivalents of oxygen. The formation of indifuscine from oxindicanine takes place in consequence of the separation from the latter of 1 equivalent of indiglucine, 4

equivalents of carbonic acid, and 3 equivalents of water, in accordance with the following equation:—

$$1\,\text{eq. Oxindicanine } C_{40}H_{23}NO_{32} = \begin{cases} C_{24}H_{10}NO_9 & 1 \text{ eq. Indifuscine.} \\ C_{12}H_{10}O_{12} & 1 \text{ eq. Indiglucine.} \\ C_4 O_8 & 4 \text{ eqs. Carbonic acid.} \\ H_3 O_3 & 3 \text{ eqs. Water.} \end{cases}$$

$$\overline{C_{40}H_{23}NO_{32}}$$

The acetic acid which is produced when indifuscine is formed from indicanine does not make its appearance in this case. Indeed the 8 equivalents of oxygen which indicanine absorbs in its conversion into oxindicanine is just sufficient when added to the oxygen already contained in 1 equivalent of acetic acid to convert the carbon and hydrogen of the latter into carbonic acid and water.

When a solution of indican is evaporated in contact with the air with the assistance of heat, and the residue which remains is treated with strong alcohol there is left undissolved a brown glutinous substance, which has the properties of oxindicanine but a different composition. The lead compound of this substance was prepared by dissolving the latter in water adding acetate of lead, decomposing the precipitate with sulphuretted hydrogen, adding a little acetate of lead to the filtered liquid, filtering again and precipitating completely with sugar of lead. The precipitate which was of a dirty yellow colour was filtered off, and washed first with water and then with alcohol.

I. 1.3345 grm. dried first in vacuo and then at 100° C. gave 0.9875 grm. carbonic acid and 0.2370 water.

1.5825 grm. gave 0.4305 grm. chloride of platinum and ammonium.

0.8960 grm. gave 0.6630 grm. sulphate of lead.

II. 1.3675 grm. of another preparation gave 1.0485 grm. carbonic acid and 0.2470 water.

1.5955 grm. gave 0.4325 grm. chloride of platinum and ammonium.

0.8895 grm. gave 0.6485 grm. sulphate of lead.

These numbers lead to the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon.....	28	168	20.27	20.18	20.91
Hydrogen...	16	16	1.93	1.97	2.00
Nitrogen	1	14	1.68	1.70	1.70
Oxygen.....	23	184	22.22	21.71	22.35
Oxide of Lead	4	446.8	53.90	54.44	53.04
		828.8	100.00	100.00	100.00

The following table shows the composition of the substance after deducting the oxide of lead as compared with that required by theory:—

	Eqs.		Calculated.	I.	II.
Carbon.....	28	168	43.97	44.29	44.52
Hydrogen...	16	16	4.18	4.32	4.25
Nitrogen	1	14	3.66	3.73	3.62
Oxygen.....	23	184	48.19	47.66	47.61
		382	100.00	100.00	100.00

This body may for the sake of distinction be called *Oxindicasine*. It is formed from oxindicanine by the latter taking up water and losing 1 equivalent of indiglucine, since

$$\left.\begin{array}{ll} 1\text{ eq. Oxindicanine} & C_{40}H_{23}NO_{32} \\ 3\text{ eqs. Water} & H_3\ O_3 \end{array}\right\} = \left\{\begin{array}{ll} C_{28}H_{16}NO_{23} & 1\text{ eq. Oxindicasine} \\ C_{12}H_{10}\ O_{12} & 1\text{ eq. Indiglucine.} \end{array}\right.$$

$$C_{40}H_{26}NO_{35} \qquad C_{40}H_{26}NO_{35}$$

It is possible that there may exist a body which bears to oxindicasine the same relation that indicanine does to oxindicanine. This body would be *Indicasine*, and would differ from indicanine by containing the element of 1 equivalent of indiglucine less. The following analyses of a lead compound which was obtained as a pale yellow precipitate when a large quantity of alcohol was added to the liquid filtered from the lead compound of oxindicasine, seem to countenance the idea that such a body really exists.

I. 0.9705 grm. of this precipitate, after being completely washed with alcohol and then dried, at first in vacuo and then

at 100° C. gave 0.5740 grm. carbonic acid and 0.1645 water.

1.2145 grm. gave 0.1210 grm. platinum.

0.6325 grm. gave 0.5420 grm. sulphate of lead.

II. 1.3280 grm. of another preparation gave 0.7795 grm. carbonic acid and 0.2145 water.

1.5600 grm. gave 0.1435 grm. platinum.

0.8965 grm. gave 0.7715 grm. sulphate of lead.

Hence was deduced the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon.....	28	168	15.90	16.13	16.00
Hydrogen . . .	20	20	1.89	1.88	1.79
Nitrogen	1	14	1.32	1.41	1.30
Oxygen.....	23	184	17.44	17.53	17.59
Oxide of Lead	6	670.2	63.45	63.05	63.32
		1056.2	100.00	100.00	100.00

After deducting the oxide of lead the composition in 100 parts as compared with the theoretical composition is as follows:—

	Eqs.		Calculated.	I.	II.
Carbon.....	28	168	43.52	43.65	43.62
Hydrogen....	20	20	5.18	5.08	4.88
Nitrogen	1	14	3.62	3.81	3.54
Oxygen.....	23	184	47.68	47.46	47.96
		386	100.00	100.00	100.00

Now if the formula of this substance be doubled and the formula of oxindicasine be deducted the remainder will be the formula $C_{28}\ H_{24}\ NO_{23}$, since

$$C_{56}\ H_{40}\ N_2\ O_{46} = C_{28}\ H_{16}\ NO_{23} + C_{28}\ H_{24}\ NO_{23}.$$

The body represented by the last formula and 1 equivalent of indiglucine contain together the elements of indicanine and water, for

$$C_{28}\ H_{24}\ NO_{23} + C_{12}\ H_{10}\ O_{12} = C_{40}\ H_{23}\ NO_{24} + 11\ H\ O.$$

It has therefore the composition which theory would assign to indicasine, and the substance represented by the formula

C_{28} H_{20} NO_{23} is probably a mixture in equal proportions of indicasine and oxindicasine. By decomposition of the lead compound with sulphuretted hydrogen and evaporation of the filtered liquid this substance is obtained in the form of a brown syrup, which cannot be distinguished in appearance or properties from oxindicanine or oxindicasine.

I did not enter into a more minute examination of these bodies, since their formation from indican is the only point of interest in their history.

XIII.—*On the Occurrence of Indigo-blue in Urine.*

By Edward Schunck, Ph.D., F.R.S.

[*Read April 7th*, 1857.]

The occurrence of urine exhibiting various peculiar and abnormal colours is a phenomenon which has frequently attracted the attention and excited the curiosity of pathologists. Of these variously tinted urines the most remarkable and striking are the black and the blue, but they are at the same time so rare, that it has been deemed of importance to record minutely the symptoms exhibited in each case as well as the chemical and physical properties shown by the urine itself. These urines have been observed in diseases of the most different kinds, as well as in cases in which the general health seemed not to be in the least degree affected. The pigments themselves, to which the colours are due, have not until lately been subjected to any chemical examination, and great doubts still prevail regarding their true nature. The blue pigment, to which I propose to confine myself on the present occasion, has been discovered in two states. In some cases it has been found ready formed so as to impart to the urine a blue colour, but merely in a state of suspension and therefore easily separated by simple filtration, whereas in other cases it has only made its appearance when the urine was left to stand or was subjected to the action

of various reagents. In the cases described by Janus Plancus,* Prout,† Braconnot,‡ and Simon,‖ it existed in the former state. Hassall developed the blue colour by means of putrefaction, in urines exhibiting the usual appearance, while Neubauer found the same effect to be produced by the addition of acids to the urine. As regards its chemical nature, the blue colouring matter seems to have been of three kinds, as far as can be ascertained from the descriptions given by the observers, which are not always very precise. In some cases, such as those described by Julia-Fontenelle,§ and Cantu,¶ the colour was evidently caused by Prussian blue, the iron of which appears to have been derived in one case from a quantity of ink which the person had swallowed. The second kind of colouring matter has been minutely described by Braconnot, who obtained it simply by filtering the urine from the blue deposit found suspended in it. It was a dark blue powder, insoluble in water and alkalies, only slightly soluble in alcohol and yielding no crystalline sublimate when heated. From its dissolving in acids and its being reprecipitated by alkalies and other bases, Braconnot inferred that it consisted essentially of an organic base, to which he gave the name of *cyanourine*. If the substance which he examined was pure, it seems certainly to have been of a peculiar nature. Nevertheless no one has since then observed any colouring matter which could be with certainty pronounced identical with it, though instances have been met with in which the blue colour not being caused, as it seemed, by any well-known body, has been attributed to the presence of cyanourine. In the third class of cases the blue colour was produced by a

* Commentarii Instituti Bononiensis, ad Ann. 1767.

† On Stomach and Renal Diseases. 5th ed. p. 567.

‡ Annales de Chimie et de Physique. T. XXIX. p. 252.

‖ Simon's Animal Chemistry, translated by Day. Vol. II. p. 327.

§ Archives générales de Médecine. T. II. p. 104.

¶ Journal de Chimie médicale. T. IX. p. 104.

substance, which on examination of its properties and reactions was found to be indigo-blue. Prout and Simon each mention a case in which indigo-blue was deposited from urine on standing, in the shape of a blue sediment. Neubauer* observed that the urine of a young man of 18, apparently in good health, when mixed with strong acids became first purple, then blue, and deposited a blue powder, which however he could not with positive certainty identify as indigo-blue. Hassall† was the first to point out that the occurrence of indigo-blue in urine was by no means so rare a phenomenon as had previously been supposed. The specimens of urine in which Hassall discovered it were mostly of a pale straw colour and acid. On standing they became thick and turbid and changed in colour from yellow to brown then to bluish-green, while the surface became covered with a blue scum or pellicle, which was found to consist of impure indigo-blue. Hassall considers that the exposure of the urine to the oxygen of the atmosphere is essential for the formation of the colouring matter, however I shall show that this exposure is by no means necessary. He also maintains that indigo-blue does not occur in healthy urine, that its presence is accompanied with strongly-marked symptoms of deranged health, and that its formation in urine must be regarded as a strictly pathological phenomenon, conclusions which are, as will be seen, quite at variance with the results of my experiments.

Such in a few words is the present state of our knowledge on this rather obscure subject.

In my paper "On the Formation of Indigo-blue,"‡ I have shown that the colouring matter exists in plants in a very different state to what had hitherto been supposed, that it does

* Anleitung zur Analyse des Harns. S. 19.

† Proceedings of the Royal Society, Vol. VI. p. 327; and Philosophical Transactions for 1854, p. 297.

‡ Memoirs of the Literary and Philosophical Society of Manchester, Vol. XII., p. 177; and "On the Formation of Indigo-blue," in the present Vol.

not exist in them ready formed nor as reduced indigo, and that the presence of oxygen is not essential to its formation, but that it owes its origin to the presence of a peculiar substance, soluble in water, alcohol and ether which by the action of acids is decomposed into indigo-blue, to which I have given the name of Indican, also a peculiar kind of sugar and a small quantity of other products. After having investigated the properties of this substance and its products of decomposition, I conceived it to be a matter of great interest to ascertain in what state indigo-blue exists in those urines, in which its presence is not indicated by the external appearance but is only made manifest by treatment with various reagents. That such urines should contain a body resembling indican seemed indeed exceedingly probable, since the same reagents which produce indigo-blue from indican lead in most cases to the development of the blue colour in particular kinds of urine. The extreme rarity however of these kinds of urine appeared to present an insuperable obstacle to the further investigation of the subject, and I therefore resolved to astertain whether any conclusions could be arrived at from an examination of ordinary healthy urine.

When muriatic or sulphuric acid is added to urine, the mixture on being heated becomes brown and begins to deposit dark brown flocks, which increase in quantity when the heating is continued. When these flocks are filtered off, washed and dried, they form a compact dark brown mass, from which cold alcohol extracts a resinous matter, leaving undissolved a brown powder, which dissolves however in a boiling mixture of alcohol and ammonia. This powder contains nitrogen and so much resembles indifuscine, one of the products of the decomposition of indican, as almost to lead one to suspect their identity. Its composition however, though it stands, as I have ascertained, in a certain relation to that of indigo-blue, is quite different from that of indifuscine. Now if the liquid filtered from these flocks be mixed with a salt of oxide of

copper and an excess of caustic soda, it becomes greenish, and if after being filtered it be heated for some time it gradually deposits a tolerably large quantity of suboxide of copper, which is a proof of the presence of sugar. That the latter has been formed during the process and did not pre-exist, may be ascertained by previously heating a portion of the urine with a salt of copper and caustic soda, before treating the remainder of it with acid. Samples of urine, which, when tried in this way, afforded very doubtful or no indications of their containing sugar, were found after being boiled with acid, then filtered and made alkaline, to reduce oxide of copper in a very marked manner. This reaction, which is so simple that it is only surprising it should never before have been observed, seems to me to prove that there is contained in urine some body, which by decomposition with acids yields sugar, the brown flocks precipitated at the same time being probably the substance with which the sugar was originally associated in the form of a copulated compound. From various considerations, which I need not detail, I was led to infer that this body could be no other than the very imperfectly known, so-called extractive matter of urine, and I accordingly commenced an investigation of this substance, which has led to conclusions of considerable interest. On discovering that the composition of the brown flocks formed by the action of strong acids on urine is expressed by the formula C_{14} H_7 NO_4, which is also that of anthranilic acid, a product of the decomposition of indigo-blue, no further considerations were necessary to induce me to proceed with the investigation, notwithstanding the difficulties which I found attending it. Into the details of this investigation I shall at present only enter so far as they relate to the occurrence of indigo-blue in urine.

When acetate of lead is added to urine it produces a cream-coloured precipitate, which consists of chloride, sulphate, phosphate, and urate of lead, and contains also a little of the extractive matter of urine, which is, as it were, merely attached

to some of these lead compounds, since it is not precipitated from its watery solution by acetate of lead, when in a state of purity. The filtered liquid which is much paler in colour than it was before the addition of acetate of lead, gives with basic acetate of lead a second precipitate of a pale cream-colour, which consists of the lead compound of the extractive matter mixed with some basic chloride of lead. Both this and the first precipitate give when treated with sulphuric or muriatic acid yellow liquids, which after being filtered from the sulphate or chloride of lead and boiled, yield brown flocks exactly like those obtained from urine itself. The liquid filtered from the precipitate with basic acetate of lead is almost colourless. It gives, however, on the addition of ammonia an almost white precipitate, the quantity of which is much less than that of either of the two other precipitates. Now this precipitate exhibits a very remarkable peculiarity. It contains in most instances in combination with oxide of lead, a small quantity of a substance which by decomposition with acids yields indigo-blue. The first time that I treated this precipitate with acid I was surprised to observe that the liquid became immediately of a purplish-blue colour, and deposited after filtering and standing a small quantity of a substance, which on examination was found to consist chiefly of indigo-blue. This phenomenon was observed on so many occasions that I came to the conclusion that the occurrence in urine of an indigo-producing body similar to indican, was by no means an unusual circumstance.

In order to ascertain whether this body is present, I adopt the following method. The urine having been mixed with basic acetate of lead until no more precipitate is produced is filtered, and after the precipitate has been washed with water the liquid is mixed with an excess of ammonia, which always produces more or less of a white or yellowish-white precipitate. This precipitate is collected on a filter, slightly washed with water and then treated with dilute sulphuric or muriatic acid

in the cold. After the whole of the oxide of lead has combined with the acid employed, the liquid is filtered. When there is much of the indigo-producing body present the filter acquires a blue tinge, small particles of blue pigment are seen dotting the surface of the sulphate or chloride of lead, and the surface of the liquid, which is of a brownish-purple colour, in a very short time becomes covered with a thin pellicle, which is blue by transmitted and copper-coloured by reflected light, particles of the same blue substance being at the same time found attached to the sides of the vessel. When there is less of the indigo-producing body present, this pellicle only appears after some time, sometimes not until the next day. After twenty-four hours however the action of the acid is always completed, so that if no indigo-blue then appears or can be detected on examination of the deposit, the total absence of the indigo-producing body may be inferred. On the succeeding day, however large the quantity of blue deposit formed may be, the liquid no longer appears purplish, but brown, and after being filtered and boiled deposits a dark brown powder, having exactly the same appearance as that produced by the action of acids on the ordinary extractive matter of urine. The matter left on the filter after being washed is treated with caustic soda, which dissolves a portion acquiring thereby a brown colour. The portion which remains undissolved after being again collected on a filter and washed, is treated with boiling alcohol. In most cases the alcohol acquires thereby a bright blue colour. When however the quantity of deposit formed is tolerably large, the boiling alcohol first dissolves another substance, which imparts to it a fine purple colour, and which I consider to be identical with indirubine.* That which the boiling alcohol leaves undissolvd is a bright blue powder having the properties of indigo-blue.

* It is very probable that Heller's urrhodine, as well as Golding Bird's purpurine are also identical with indirubine, which, as I have shown, has the same composition as indigo-blue.

It dissolves in an alkaline solution of protoxide of tin, and the solution on exposure to the air becomes covered with a blue film. It is soluble in concentrated sulphuric acid forming a blue solution, which remains blue even after dilution with water. It imparts to boiling alcohol a bright blue colour, and the solution on cooling and standing deposits blue flocks. When heated in a tube it gives a purple vapour which forms on the colder parts of the tube a blue sublimate.

Provided with this test I proceeded to examine the urine of a number of individuals, and I succeeded in obtaining indigo-blue in so great a number of instances, that I have no hesitation in saying that the indigo-producing body, if not exactly one of the normal constituents of urine, occurs more frequently than any other of the abnormal ones. The urines containing it exhibit no remarkable or peculiar appearance whatever; they are acid, clear, and of the usual colour. Its occurrence, at least if its quantity is moderate, is not to be considered as a pathological phenomenon. I can at all events state from my own experience, that its presence is not attended by any symptoms of ill health or feelings of discomfort, and that neither from the state of the health nor the appearance of the urine can any conclusions be drawn as to its presence or absence. The small number of samples of morbid urine, which I had an opportunity of examining, yielded, with one exception, no more indigo-blue than the generality of healthy urines. Nevertheless, there are no doubt diseases in which the quantity of the indigo-producing body may become so large as to constitute a truly morbid symptom, and it may therefore become a matter of importance and interest for the medical man to have a ready means of detecting it. The delicacy of the test which I have described, as well as the small quantity of the substance usually present, may be judged of from the fact that by working for several weeks on the urine of two individuals, which contained a comparatively large quantity, I obtained one grain of indigo-blue. Even

when the amount of indigo-blue formed was very small I always found that 16 fluid ounces of urine yielded an appreciable quantity of it.

The urine of forty different individuals, all of whom were apparently in a good state of health, yielded, with one exception only, more or less indigo-blue, when examined in the manner just described. These individuals belonged to both sexes, and they were of ages varying from 7 to 55. The majority were persons of the working classes. The largest quantity of indigo-blue was obtained from the urine of a man above the age of 50, a publican by trade. The urine of a young man, aged 32, a servant in my employment, yielded almost as large a quantity. Among the rest, the urine of a young man, aged 25, an engraver, that of a clerk, aged 23, and that of a girl, aged 12, who had been a cripple from infancy, were alone remarkable for the amount of indigo-blue which they yielded. In all these cases the indigo-blue was accompanied by the substance imparting to alcohol a purple colour, and which I suppose to be indirubine. The other specimens afforded much less, sometimes mere traces. In all cases however in which the urine of the same individual was examined at different times, the amount of indigo-blue obtained from it was found to vary exceedingly, it being sometimes considerable and occasionally dwindling down to a mere trace. It was only very rarely however that none was found. In the case of the individual first referred to, the urine gave on one occasion not a trace, and this took place when he was engaged in performing labour, unusual for him both in its nature and amount. In my own case, as well as that of my assistant, the amount varied most capriciously from a tolerable quantity to a mere trace, occasionally even none at all being obtained.

I performed several experiments with different kinds of diet in order to ascertain the effect on the amount of indigo-blue yielded by the urine. Only one experiment, however, led to any decisive result. Having selected an occasion, when the

night urine gave no indigo-blue, I took on the next night, before going to bed, a mixture of treacle and arrowroot boiled with water in as large a quantity as the stomach could bear, and the effect was that the urine of the following night gave a large quantity of indigo-blue. As, however, the same phenomenon was repeated for several succeeding nights without any additional quantity of food having been taken, it remained uncertain to what cause it was to be attributed, though a repetition of the experiment on a second occasion gave the same result.

I have hitherto not had an opportunity of examining many specimens of urine in disease. Of two samples of urine from patients with albuminaria one gave a small quantity of indigo-blue, the other not a trace. Several specimens of diabetic urine yielded it. One of these, which I owed to the kindness of Dr. Browne of Manchester, gave a much larger quantity than I obtained from any other specimen of human urine.

The urine of the horse and the cow when tried in the same way as human urine gave comparatively very large quantities of indigo-blue, especially that of the horse.

I think it is highly improbable that the indigo-blue obtained in Hassall's experiments was produced, as he supposes, by the action of oxygen on the urine. Its formation was without doubt due to the decomposition of the indigo-producing body induced by the fermentation of the urine, the indigo-blue at the moment of its formation dissolving in the fermenting alkaline liquid and producing a true indigo vat, from which it was gradually deposited by the action of the atmospheric oxygen. When small quantities of indigo-blue only are formed in any specimen of urine, fermentation is not in my opinion to be recommended as a means of detecting it.

The occurrence of the indigo-producing body as an excretion seems to me to be due to a disproportion between the oxygen absorbed by the system and the matter to be acted on by it, which again may be caused either by an excessive

waste of the tissues or by an obstruction of the organs conveying oxygen, as the lungs and skin, or, as is probably the case in the majority of instances, by an excess of food being taken over and above the requirements of the system. As regards the constitution of this body, I think there can be no doubt that it contains the elements of indigo-blue and sugar, and that by oxidation within the system it is converted into the ordinary extractive matter of urine, which contains, as I have ascertained, the elements of sugar and of the black substance which is formed by the action of strong acids on urine, and which may be considered as a product of the oxidation of indigo-blue. Having prepared the extractive matter of urine in a state of purity, ascertained its composition, and examined its products of decomposition, I think it is probable that the indigo-producing body will be found, as regards its formation and composition, to occupy a place between the substance of the tissues and the ordinary extractive matter of urine. The very minute quantities of it ordinarily occurring in urine, and the difficulty of separating it from the extractive matter, make it, however, impossible to ascertain whether this is the case or not. My object in making known this portion of the investigation in its present fragmentary state, is to induce medical men, who have an opportunity of examining many varieties of urine, to endeavour to discover among these varieties some containing a sufficiently large quantity of this body to enable the chemist to ascertain its properties and composition.

The formation of a substance containing the elements of indigo-blue in the animal system is a fact which may lead to important conclusions regarding the chemical composition of the complex bodies of which the blood and tissues consist.

SESSION 1856–1857.

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MANCHESTER... *Photographic Society:* Photographic Illustrations. No. I.

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